Naval Submarine Medical Research Laboratory

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TRANSIENT-EVOKED OTOACOUSTIC EMISSIONS

PRELIMINARY RESULTS FOR VALIDITY OF TEOAEs IMPLEMENTED ON MIMOSA ACOUSTICS T2K MEASUREMENT SYSTEM v3.1.3

by

Judi A. Lapsley Miller, Paul Boege,
Lynne Marshall, and Patricia S. Jeng

Released by:
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SUMMARY

The Problem
The validity of transient-evoked otoacoustic emissions needed to be determined for click and chirp stimuli implemented on the Mimosa Acoustics T2K Measurement System.

The Findings
The validity of transient-evoked otoacoustic emissions was evaluated for the Mimosa Acoustics T2K Measurement System v3.1.3 in eight hearing-impaired ears. These ears should not produce TEOAEs, so any responses are likely to be due to measurement artifact. Click and chirp stimuli showed acceptable validity for stimulus levels from 38 to 50 dB SPL when the stimuli were presented in the nonlinear mode.

Application
Transient-evoked otoacoustic emissions are sounds made by healthy inner ears to transient stimulation. They are thought to hold the potential for diagnosis and monitoring of noise-induced hearing loss in military hearing-conservation programs. Choosing TEOAE stimuli for use in hearing-conservation programs must include considering the validity of the measurement. This is to ensure that the measured TEOAEs are due to responses made by the inner ear and are not artifacts.

Administrative Information. “This work was conducted under Work Unit # 50309, entitled “Evoked Otoacoustic Emissions in Military Hearing Conservation Programs.” The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of the Navy, Department of Defense, or the United States Government. This research has been conducted in compliance with all applicable Federal Regulations governing the Protection of Human Subjects in Research.” This Technical Report was approved on March 15, 2004, and designated as NSMRL Technical Report #TR1232.

TRANSIENT-EVOKED OTOACOUSTIC EMISSIONS

PRELIMINARY RESULTS FOR VALIDITY OF TEOAES IMPLEMENTED ON MIMOSA ACOUSTICS T2K MEASUREMENT SYSTEM V3.1.3

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ABSTRACT

The validity of transient-evoked otoacoustic emissions (TEOAEs), as implemented on the Mimosa Acoustics T2K Measurement System (v. 3.1.3), was assessed for a variety of transient stimuli. Stimuli evaluated included clicks, Dau chirps, and Shera chirps, all with bandwidth 1 to 5 kHz and stimulus levels from 38 to 53 dB SPL, and clicks with bandwidth 1 to 2.5 kHz. A new form of in-the-ear calibration was used that corrected the stimulus to give the desired spectrum and group delay. Both linear and nonlinear modes were evaluated. Validity testing was done using moderate-to-profoundly hearing-impaired ears, which should not produce TEOAEs. Any measurable response is an indication of artifact. Validity was established for all TEOAE stimuli up to 50 dB SPL(rms) when testing was done in nonlinear mode. Validity could not be established for any stimulus when testing was done in linear mode, where linear artifact was not subtracted out. Spectral calibration showed more artifacts at lower frequencies and fewer artifacts at higher frequencies, when compared with wideband calibration for clicks measured in linear mode. Chirp stimuli produced fewer artifacts than clicks, presumably due to their lower crest factors and longer durations. Minor enhancements to the spectral calibration should improve validity further.

ACKNOWLEDGEMENTS

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INTRODUCTION

Mimosa Acoustics have implemented a transient-evoked otoacoustic emissions (TEOAE) measurement system, similar in concept and execution to that by Bray and Kemp at ILO (Bray, 1989; Kemp, Ryan, & Bray, 1990). Mimosa has made significant technological advancements in TEOAE measurements, including

- Ability to set up custom stimuli by varying bandwidth, magnitude spectrum, and group delay to make a variety of clicks and chirps.

- A new form of in-the-ear calibration that compensates for individual ear canal and probe differences.

- Speed of data acquisition has quadrupled.

- The noise floor is much lower than in the ILO system.

Preliminary comparisons in an acoustic coupler showed that the Mimosa TEOAE system had a lower noise floor and fewer artifacts than the ILO system. Our application is hearing conservation where measurements are made in ears that often have low-level TEOAEs. It is important to be able to make quality measurements in these ears. Low-level TEOAEs are measurable if the noise floor is low and there are few to no artifacts. Furthermore, a lower noise floor means that a lower TEOAE stimulus level can be used; TEOAEs evoked with low stimulus levels are thought to be more sensitive to noise-induced changes (Marshall & Heller, 1998; Sutton, Lonsbury-Martin, Martin, & Whitehead, 1994).

Here, we consider whether the Mimosa system produces valid TEOAE measurements in severely hearing-impaired ears. No TEOAEs should be measurable in such ears. If “TEOAEs” are present, then they are considered artifacts of the measurement system. The reason for using hearing-impaired ears is because measurements in an acoustic coupler indicate only what might happen in an average ear. Measurements made by Heller and Marshall (unpublished data) using the ILO system have shown that hearing-impaired ears sometimes show artifact which is not apparent in an acoustic coupler.

TEOAE STIMULI

As well as the traditional click stimulus, Mimosa Acoustics also provide two types of chirp stimuli (see Figures 1, 2, & 3). The chirp stimuli are based on those by Dau and Shera (Dau, Wegner, Mellert, & Kollmeier, 2000; Shera, Guinan, & Oxenham, 2002). The time course of Dau’s chirp is designed for simultaneous displacement at all frequencies by compensating for travel time differences on the cochlear partition. The derivation of the chirp was based on a linear cochlear model by de Boer (Dau et al., 2000). Its use so far has primarily been as an ABR stimulus. It has been suggested that the chirp stimulus could produce TEOAEs with higher SNR than the click stimulus (Medri & Ozdamar, 2000).

Shera's chirp has about twice the group delay of Dau's chirp (see Figure 2), and therefore a longer duration (see Figure 3). It is based on measurements of stimulus-frequency OAEs (Shera et al., 2002). Its duration represents the travel time on the basilar membrane, both inwards and outwards. Theoretically, it would cause the response to compress in time and become more click-like.

It is unknown which of these stimuli is best as a TEOAE stimulus (e.g., best signal-to-noise ratio of the TEOAE, fewest artifacts/best validity, best reliability, etc.). Here, we consider the validity of TEOAE measurements made with bandlimited clicks and chirps. The bandwidth is identical for all and is set for 1 to 5 kHz. A comparison of the spectra (see Figure 1) shows that the spectra are essentially identical (these examples are from Subject 1024 using spectral calibration). However, the group delays are different (see Figure 2), as is the duration and shape of the stimuli in time (see Figure 3). The click stimulus is most compressed in time, with a duration of about 5 ms. The Dau chirp starts from low frequencies and moves to high frequencies over about 9 ms. The Shera chirp is similar to the Dau chirp, but the duration is about 12 ms.

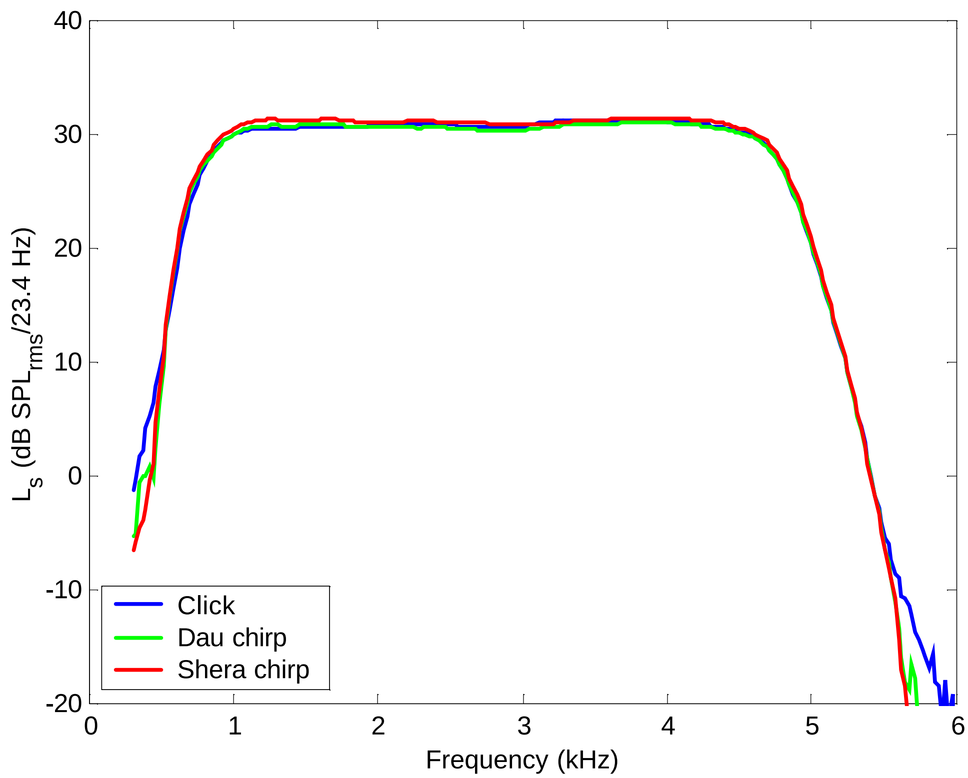

Figure 1. Comparison of spectra for the click, Dau chirp, and Shera chirp, all designed with the same bandwidth parameters (1 to 5 kHz) and measured in-the-ear after spectral calibration.

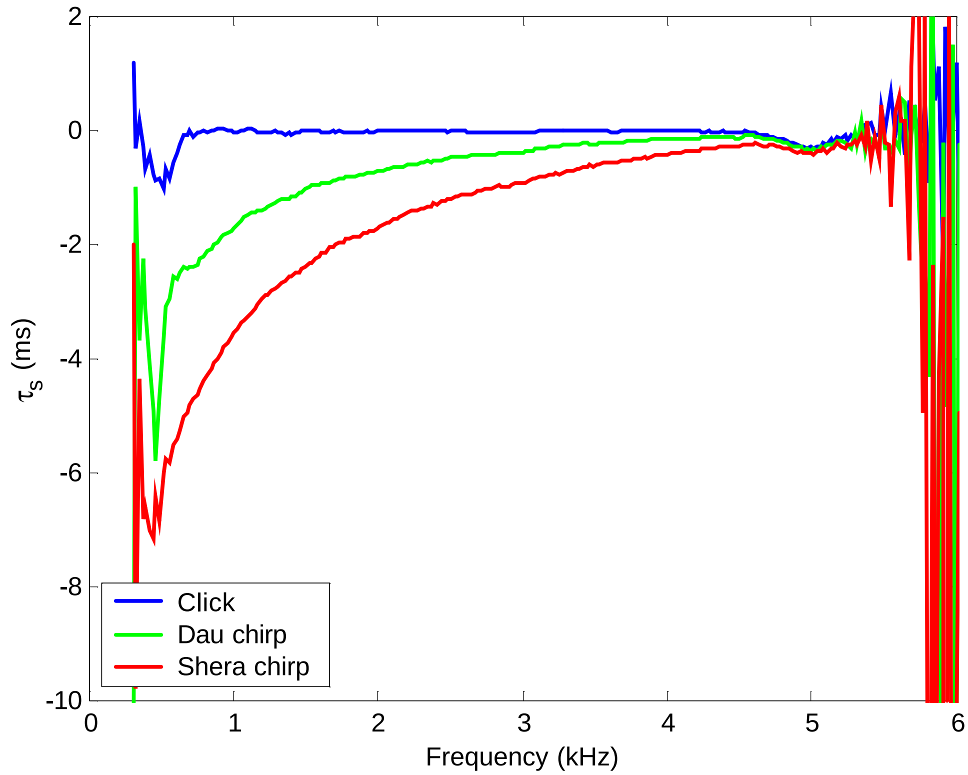

Figure 2. Comparison of group delay for the three stimuli from Figure 1. This plot shows at what point in time each frequency is produced.The spectral calibration manipulates the magnitude and group delay to the desired characteristics from just below to just above the frequency cutoffs. Group delays above and below these cutoffs are not corrected (but are typically low magnitude).

CALIBRATION

Two types of calibration can be chosen. One, referred to here as "normal calibration," measures the wideband stimulus level in-the-ear and applies a voltage correction to obtain the target stimulus level. The other, referred to here as "spectral calibration," takes the results of the normal calibration and applies magnitude and phase correction (in the frequency domain) to obtain the desired stimulus *spectrum* and *level*. This process attempts to account for differences among probes and among ears. This is particularly important for the ER10C probe, because unlike the ILO probe, it does not have a flat impulse response. It is hoped that spectral calibration will also produce more reliable results.

SUMMARY

The validity of the Mimosa TEOAE system will be assessed for a variety of click and chirp stimuli presented at stimulus levels from 38 to 53 dB SPL. The aims are to find the highest artifact-free stimulus level for each stimulus and to examine the cause of any artifacts found.

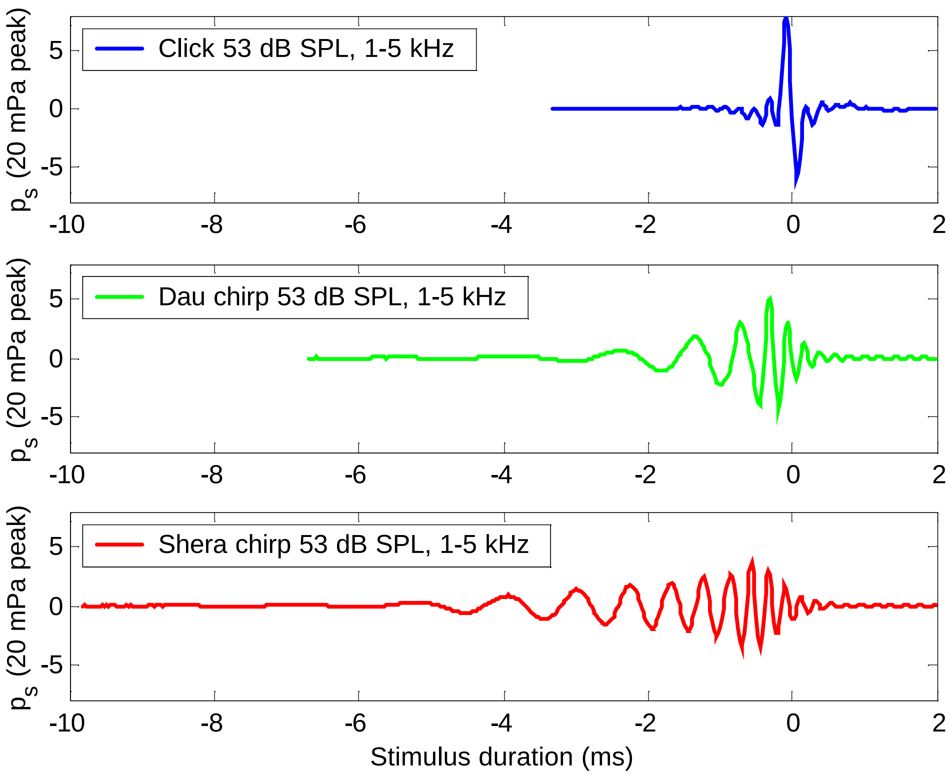

Figure 3. Comparison of stimulus duration for the three stimuli from Figure 1.

METHOD

SUBJECTS

Eight people with moderate-to-profound hearing impairments in at least one ear were enrolled (5 male and 3 female participants, aged 14 to 80 years).

SCREENING

The etiology of all hearing losses was consistent with sensorineural hearing loss (excluding Meniere's disease). The hearing losses were at least 50 dB HL at the frequencies 0.5, 1, 2, 3, 4, 6, and 8 kHz. It is highly unlikely that there would be any EOAEs present in ears with hearing loss to this degree across all of these frequencies.[1] If both the participant's ears met the criteria then the most impaired ear was chosen for testing.

An otoscopic examination was done to ensure ear canals were clear (no cerumen), and that there were no external ear pathologies. Cerumen removal was done where necessary before any EOAE testing. Middle-ear pressures were required to be between ±50 daPa for OAE testing.

[1] Dorn et al (2001) showed some hearing-impaired participants with EOAEs. These participants had hearing levels of at least 50 dB HL at the test frequency, but not necessarily across a wider frequency range as we require.

All hearing-impaired ears were tested for the absence of distortion-product OAEs (DPOAEs). Ears with this type and degree of hearing loss do not have DPOAEs (absence defined as no DPOAE level 10 dB above noise). Parameters used were L_1/L_2=65/55 dB SPL and f_2/f_1 =1.21 (Stover, Gorga, Neely, & Montoya, 1996). f_2 ranged from 1 to 4 kHz with 10 points/octave for a total of 21 test points. The Mimosa Acoustics DP2000 system was used for testing.

TEOAE MEASUREMENTS

The Mimosa Acoustics T2K Measurement System (version 3.1.3) was used for all TEOAE testing. The TEOAE measurement system consisted of a 16-bit digital signal processor (PCMCIA card) and an ER10C probe (S/N 1210). The system was run on an IBM ThinkPad laptop.

All OAE measurements were made in a certified, calibrated, IAC sound-attenuating chamber. The laptop and OAE equipment were in the booth with the subject. The examiner controlled the testing from outside the booth by using an extender setup (which allowed remote control of the keyboard, mouse, and screen).

Each protocol took approximately 60 seconds to run, depending on how many averages were rejected.

Table 1. The transient stimuli were tested in both linear and non-linear modes. The 1 to 5 kHz click was also evaluated in linear mode with normal calibration.

Stimulus	Bandwidth (kHz)	RMS Stimulus Level (dB SPL)	Peak Stimulus Level[2] (dB pSPL)	Description
Click	1 to 5	53, 50, 47, 44, 41, 38	78, 75, 72, 70, 67, 64	Spectral calibration, (linear and nonlinear modes)
Click	1 to 5	53, 50, 47, 44, 41, 38	78, 75, 72, 70, 67, 64	Normal calibration (linear mode only)
Click	1 to 2.5	53, 50, 47, 44, 41, 38	76, 73, 70, 67, 64, 61	Spectral calibration, (linear and nonlinear modes)
Dau Chirp	1 to 5	53, 50, 47, 44, 41, 38	74, 71, 68, 65, 62, 59	Spectral calibration, (linear and nonlinear modes)
Shera Chirp	1 to 5	53, 50, 47, 44, 41, 38	71, 68, 65, 62, 59, 56	Spectral calibration, (linear and nonlinear modes)

[2] Estimated from results of the in-the-ear spectral calibration.

Table 1 outlines the transient stimuli investigated for TEOAE validity. The 1 to 2.5 kHz Click is a potentially interesting stimulus for TEOAE contralateral suppression.

To optimize data collection time, TEOAEs were measured at the highest level and then dropped down in 3 dB increments until the results were clean (no response greater than 3 dB above the noise floor in a half-octave band). The testers were asked to keep testing if they were unsure whether there was any artifact present.

TEOAE stimulus level was defined in rms SPL rather than peak SPL (pSPL), to allow for appropriate comparisons amongst clicks and chirps. The equivalent pSPL depends on the stimulus type and bandwidth (approximate, equivalent pSPL values are shown in Table 1). The crest factor (peak to rms ratio) is lower for chirps than clicks.

Clicks using normal calibration were added into the protocol once data collection had begun. For two subjects, measurements were made only at the highest level.

PARAMETERS

- Stimulus level = 53, 50, 47, 44, 41, 38 dB SPL.
- Linear and nonlinear modes. In linear mode, all stimuli are presented at the same stimulus level. In nonlinear mode, the stimuli consist of an ensemble of 4 waveforms: 3 at the same stimulus level and one at 3 times the stimulus level but with reverse polarity. The TEOAE response from the large waveform is subtracted from the combined response to the three small waveforms. In a truly linear system, the result should equal zero. If the system is non-linear (like the OAE system) then there should be a residual, which is considered to be an OAE. Most TEOAE artifacts tend to be linear, so are removed using this technique, but at the price of also removing the linear OAE response.
- Non-linear: number of averages = 500 (3×1 up, 1×3 down; 2000 waveforms in total)
- Linear: number of averages = 2000

The order of presentation was the same for each subject, set in order of priority rather than counterbalancing. This was due to limited available time with each subject.

Stimuli were designed in “Custom” mode, with identical bandwidth parameters, but the clicks and two chirps designed by manipulating group delay (see Technical Documentation). The inter-stimulus interval was 20 ms throughout. The gain was set to 0 dB for linear and 18 dB for non-linear. These values were determined by coupler measurement (there is a noise-floor versus artifact trade-off, which differs for linear and nonlinear modes).

RESULTS

The overall aim was to find the highest artifact-free level for each stimulus type, both on a wideband and a half-octave-band basis. It was not always possible to establish unambiguously which level was artifact free. This was usually due to missing data. Data may have been missing due to high noise levels or too few averages being taken (which is also usually due to high noise levels). In these cases, the next stimulus level down was chosen, but it was indicated if there was a possibility that the higher level may have been artifact free (see Appendices).

It was not possible to analyze averaged results in any consistent fashion, because due to the "expedited" procedure, subjects were not necessarily tested at all levels. Even for levels where there were data for all subjects, there were still only 8 data points in each frequency band available for averaging.

DATA CLEANING

There were a total of 281 measurements. Each measurement was examined to establish that the stimulus level was within 2 dB of the target level (all measurements met this criterion) and that at least 90% of the averages were achieved (15 measurements were dropped). In these latter cases, the maximum test time criterion was reached and/or the maximum number of rejections was reached before achieving the required number of averages. This typically happened if many averages were rejected because the noise level was too high (due to the subject moving, coughing, breathing loudly, etc).

The data cleaning was done without examining the "OAE" response.

DATA REPROCESSING

During data collection, the data window and filters were set to pass more signal than what would normally be used. This was to ensure that more potential artifacts were caught during data collection so that the tester would be sure to at least test the next stimulus level.

For analysis, the high-pass response filter was set to 1 kHz (to reduce low-frequency movement and body noise) and the low-pass response filter was set to 7 kHz (approximately half an octave above the highest frequency in the stimulus; this filter was used to define the upper bandlimit for the wideband analyses). The data window remained at 2 ms post-stimulus start time with an 18 ms duration, except for the 1 to 2.5 kHz Clicks where the post-stimulus start time was increased to 4 ms. This was done because the narrower bandwidth clicks had a longer duration than the wider bandwidth clicks. However, because there was no stimulus content at 3 kHz and above, there should be little to no TEOAE response at these frequencies. For true TEOAEs, higher-frequencies should have shorter latencies so will appear at the beginning of the TEOAE. For the 1 to 2.5 kHz clicks we can safely window the first 4 ms out, because we expect to see no TEOAEs at these frequencies, with the benefit of removing more stimulus artifact.

SUBJECT SUMMARY

The following is a general summary of results for each subject, focusing on the quality of the calibration and on any artifact/noise that was common across stimulus types.

SUBJECT 1024

Subject 1024's audiogram showed a flat, moderately severe sensorineural hearing loss through 2.0 kHz, abruptly falling to severe-profound at higher frequencies. In general, the TEOAE data were well behaved.

SUBJECT 1028

Subject 1028 had a cochlear implant in his right ear, and was also hearing impaired in his left ear. His right ear was chosen for testing. The audiogram showed a profound sensorineural hearing loss. The cochlear implant was turned off during testing. In general, the TEOAE data were well behaved. Note that linear Clicks (with normal calibration) were tested only at 53 dB SPL.

SUBJECT 1029

Subject 1029 had a cochlear implant in his right ear, and was also hearing impaired in his left ear. His right ear was chosen for testing. The audiogram showed a profound sensorineural hearing loss. The cochlear implant was turned off during testing. In general, the TEOAE data were well behaved. Note that linear Clicks (with normal calibration) were tested only at 53 dB SPL.

SUBJECT 1035

Subject 1035 had a bilateral hearing loss; the left ear was chosen for testing. The audiogram was gradually sloping, from moderate to profound, consistent with sensorineural hearing loss (unknown etiology, but most likely a mix of congenital, noise-induced hearing loss, and presbycusis). Many TEOAE measurements were discarded from the second half of testing (affecting linear testing for Dau and Shera chirps, and 1 to 2.5 kHz Clicks) because not enough averages were collected due to high noise levels. Data were also rejected during data cleaning, because of high noise floors, even when the required number of averages was acquired.

SUBJECT 1037

Subject 1037 was hearing impaired in both ears after childhood meningitis. She had a cochlear implant in her left ear. Her right ear was chosen for testing, because it needed less cerumen removed. The audiogram showed profound sensorineural hearing loss. TEOAE testing showed some artifact in the linear mode, especially around 2 kHz.

SUBJECT 1038

Subject 1038 had a profound, unilateral, sensorineural hearing loss after an acoustic nerve resection for removal of an acoustic neuroma. In general, the TEOAE data were well behaved with little to no missing data. (See commentary for Subject 1042 for more information.)

SUBJECT 1041

Subject 1041 had an acquired bilaterally symmetric hearing loss. The right ear was chosen for testing. The audiogram was sharply sloping, from moderately severe to profound, consistent with sensorineural hearing loss (etiology unknown). This subject had very noisy TEOAE data with some artifact. When looking at his linear Clicks without spectral calibration it becomes more apparent why. The uncorrected Click shows large loss at lower frequencies, probably due to a leak in the probe fit. The spectral calibration has to apply a large amount of correction to achieve the desired stimulus shape, but it appears that in doing so, artifact is introduced.

SUBJECT 1042

Subject 1042 had a profound sensorineural hearing loss in her left ear from acoustic neuroma surgery, and normal hearing in her right ear. It became apparent during TEOAE data analysis that some residual function possibly remained in her left ear, because some of her TEOAE tests showed OAE-like responses down to quite low stimulus levels – including in the nonlinear mode (which typically has little to no artifact). OAE-like responses were not apparent in the DPOAE or SFOAE tests; however, it is possible that the test frequencies used coincided with nulls in the SFOAE spectra. I/O functions indicated compression (see Figure 4 and Figure 5). In comparison, the artifact for Subject 1041 (who had a cochlear implant) showed linear I/O functions (see Figure 6).

Subject 1042's surgeon was contacted to establish if there was any possibility of residual cochlear function. The surgeon stated that the surgery was a suboccipital craniotomy for removal of an acoustic neuroma. Clinically, she had no hearing after the surgery. There was no clear indication of how she lost her hearing during the course of the surgery; it was presumably due to damage to the auditory nerve and perhaps also to the blood supply to the inner ear. Therefore, it is certainly possible her hearing loss was due to an isolated injury to the auditory nerve, and she may have an intact cochlea and therefore, outer hair cells. The surgeon could not be sure about this and suggested a CT scan (damage to the inner ear during acoustic neuroma surgery is usually due to damage to the blood supply and hence one would expect new bone formation within the inner ear if it had been a cochlear injury). Unfortunately, it was not possible for us to get a CT scan. The evidence presented indicates that there is a possibility that she has an intact cochlea. In comparison, Subject 1038, who was also hearing-impaired from acoustic neuroma surgery, did not have any evidence of TEOAE-like responses. Her surgery involved a combined approach – both retrosigmoid and suboccipital craniotomy. She reported being told by her surgeon that her hearing could not be preserved because the neuroma was wrapped around the eighth nerve. We assume that the cochlear artery was also damaged in the surgical procedure.

Curiously, Subject 1042 did not show a response for non-linear Shera chirps (and had a lesser response for Dau chirps). It may be a latency issue, with the response to the early low-frequency component of the chirp appearing before the chirp finished. If the responses were truly normal TEOAEs (i.e., as for a normal-hearing ear), then they should have a long delay at the low frequencies, but this does not appear to be the case here. However, it is not clear that we can apply “normal” standards to these responses produced in a hearing-impaired ear.

We do not believe that we can establish beyond reasonable doubt that this subject had no TEOAEs, so we have interpreted the results without this subject, (but we have, however, included comments about how Subject 1042 differs from the others). The tables in the Appendices give the reader the option of reinterpreting the results to include Subject 1042.

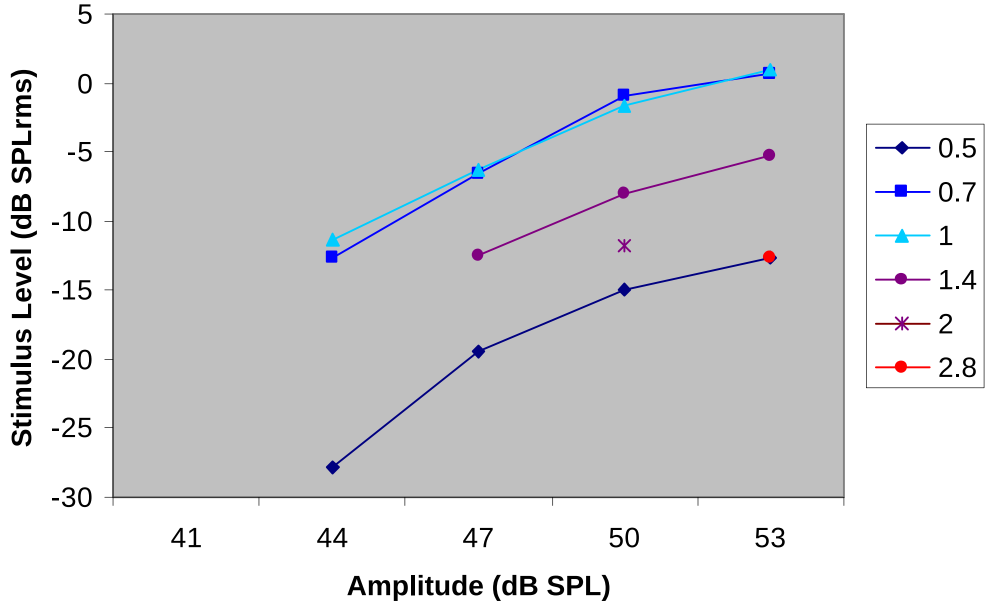

Figure 4. Input-Output Functions for Subject 1042 for nonlinear clicks. Each line indicates a half-octave frequency (kHz). Plotted are data points with SNR>3 dB. Notice the compression of the I/O functions for 0.5, 0.7, and to a lesser extent for 1 and 1.4 kHz.

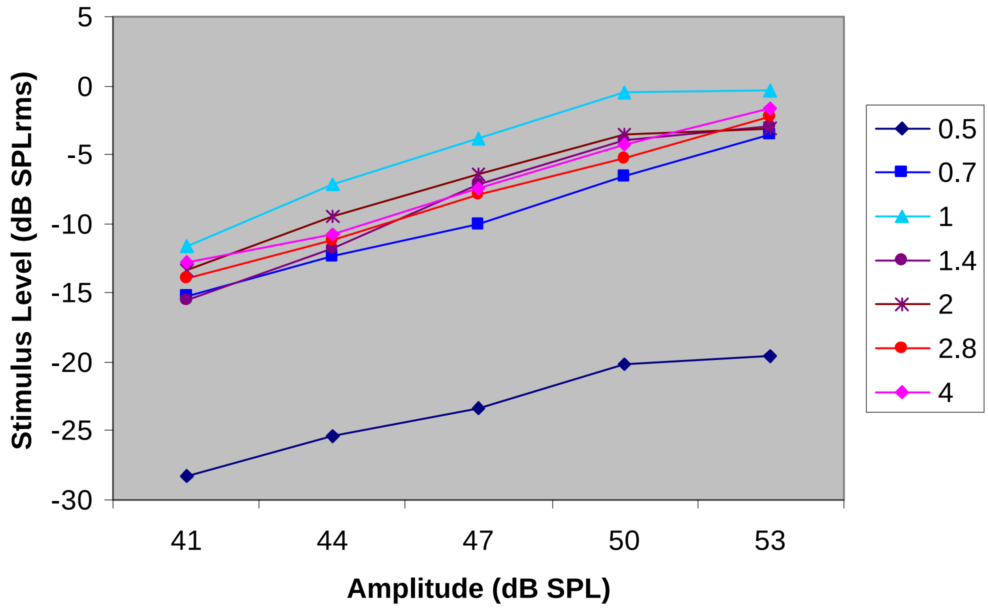

Figure 5. Input-Output Functions for Subject 1042 for linear clicks. Each line indicates a half-octave frequency (kHz). Plotted are data points with SNR>3 dB. There appears to be compression for 0.5, 1, 1.4, and 2 kHz, but no so for 0.7, 2.8, and 4 kHz.

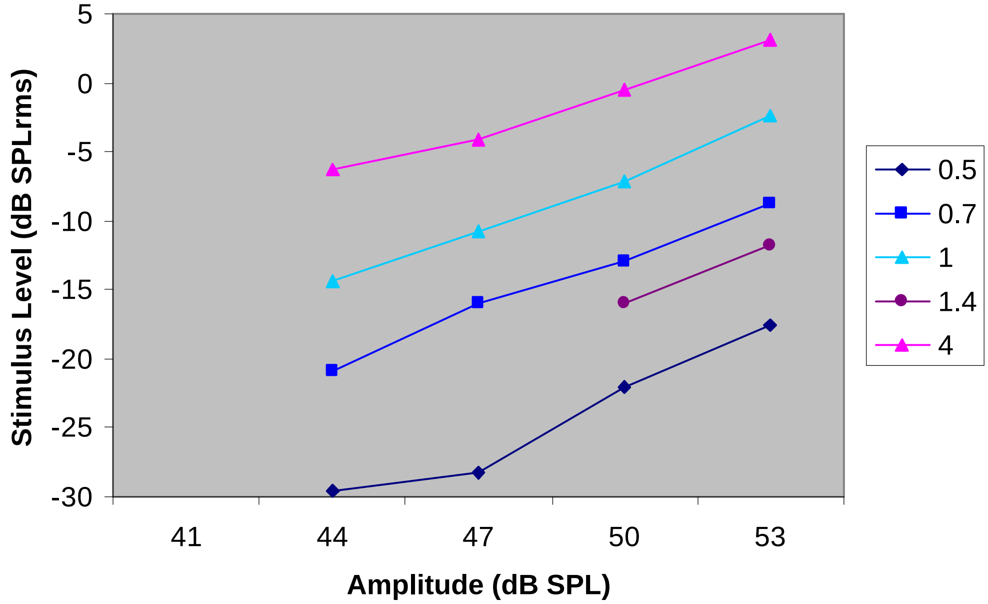

Figure 6. For comparison with Figure 5, these Input-Output functions are for the same linear Click condition but for Subject 1028. Subject 1028 showed some responses above the noise floor across level. Here the Input-Output functions are straight, indicating that the responses are due to a linear artifact, rather than an OAE (which is consistent with the fact that this subject has a cochlear implant).

NORMAL VERSUS SPECTRAL CALIBRATION

Clicks (1 to 5 kHz, linear mode) calibrated using normal rather than spectral calibration were measured to obtain the uncorrected stimulus spectrum in the ear canal. This spectrum indicated to what extent the spectral calibration needed to compensate the magnitude and group delay of the stimulus. Figure 7 shows the Click stimulus spectra for each subject, with normal and with spectral calibration, measured in the ear canal. Spectral calibration results in very consistent stimulus spectra across subjects. Normal calibration showed large differences in spectrum across subjects for the same peak SPL.

Due to time limitations, validity for the two forms of calibration was compared for only the linear Click (1 to 5 kHz) stimulus. In two cases (Subjects 1028 and 1029) for normal calibration, only the highest stimulus level was tested. Wideband results indicated fewer artifacts for the normal calibration. Particularly, Subjects 1024, 1038, and 1041 had fewer artifacts. There was more low-frequency artifact for spectral calibration in the half-octave band analysis. This is explained by the increased amplification needed at lower frequencies to adjust the stimulus spectrum, especially when a couple of calibrations appeared to indicate leaky fits. There were more artifacts at higher frequencies (4 kHz) for normal calibration. This is explained by the existence of a probe artifact in this frequency band for this particular probe (see Appendix A). In general, the ER10C probe response to a flat spectral input is not flat – it has a maximum around 4 kHz. When spectral calibration is used, the output in this frequency region is attenuated, which also reduces the artifact.

Further refinement of the spectral calibration technique should improve validity by (a) warning the operator if there is a leaky probe fit and (b) warning if adjustment needs to be made over too great a range in amplitude or group delay. It remains to be seen if the expected improvement in reliability is worth the potential increase in artifact with spectral calibration. It should also be established if artifact is an issue in the non-linear mode.

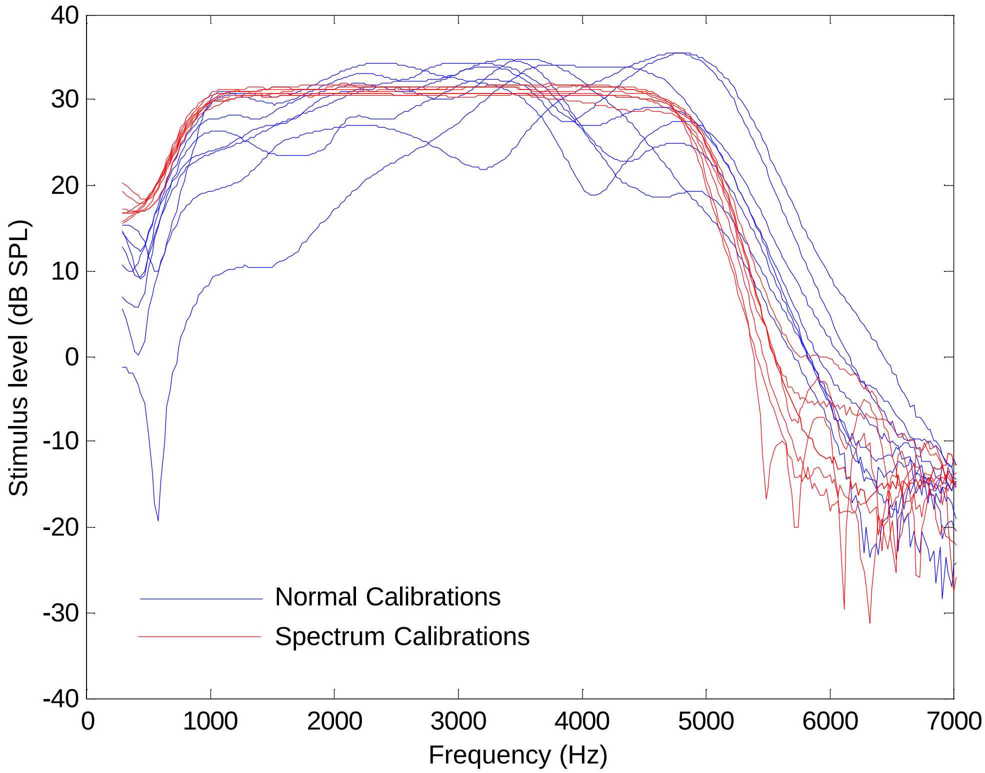

Figure 7. Normal versus Spectral calibration for linear Clicks at 53 dB SPL (eight subjects).

WIDEBAND VALIDITY

Artifact was defined as present if the wideband response was 3 dB higher than the wide-band noise floor. Data were reprocessed with a 1 kHz high-pass filter (from 800 Hz) and a 7 kHz low-pass filter. The data window started at 2 ms, with duration of 18 ms (and ramps of 2.5 ms) for all but the 1 to 2.5 kHz Clicks, which used a 4 ms starting point and a 16 ms duration.

There was some missing data due to high noise floors (wide-band noise floor greater than 0 dB SPL) and too few averages taken (generally occurring from noisy measurements where the stopping criteria for number of rejections or maximum test time was reached).

Other than for Subject 1042, whom we suspect to have a relatively intact cochlea, no nonlinear TEOAE protocol showed any artifact.

Most subjects showed some artifact for linear TEOAE protocols, especially at the higher stimulus levels. For the stimuli with bandwidth from 1 to 5 kHz, no artifact was seen for a stimulus level of 41 dB SPL (excluding Subject 1042). The 1 to 2.5 kHz Click stimulus was artifact free only at a stimulus level of 38 dB SPL (excluding Subject 1042).

Appendix B breaks these results down by subject.

HALF-OCTAVE BAND VALIDITY

Here the TEOAE measurements are reanalyzed in half-octave bands to consider artifact that may appear in specific frequency regions, but which may not be large enough to show up in the wide-band TEOAE. Furthermore, artifacts in different frequency regions may come from different sources. Measurements in a coupler show that ER10C probes tend to have a low-level resonance point (which is noticeable in linear mode). The frequency where this resonance occurs differs for each probe. The probe used here had a resonance in the 4 kHz half-octave band (see Appendix A for examples).

Data were cleaned as for the wide-band results: the stimulus level was required to be within 2 dB of target and at least 90% of the averages collected. In each half-octave band, the noise floor was required to be lower than -10 dB SPL before examining for artifact. If an artifact was found (> 3 dB SNR in the half-octave band) it was only considered important if the amplitude was greater than -25 dB SPL. The criterion of 3 dB was used to allow for random fluctuations of responses and very low-level artifacts. Elsewhere, 0 dB has been used as an SNR criterion, but we think this may be too lax, letting in too many false-positive low-level responses. Unfortunately there are not enough data available here to generate distributions of responses versus noise floor.

The aim was to find the highest artifact-free level for each TEOAE stimulus type. Conclusions were drawn by examining the pattern of artifact as the stimulus level was reduced from 53 to 38 dB SPL (in 3 dB steps). Missing, noisy, and/or ambiguous data points sometimes made it difficult to be sure the level was artifact free: such cases are highlighted in Appendix C. High noise levels can potentially hide the presence of a low-level artifact. The noise in most cases was assumed to come from subject movement and breathing. Noise rejection is done on a wideband basis, so noise contained in a narrower frequency region may not cause the wideband level to meet the criterion for rejection during testing. Appendix C gives the breakdown of the results for each subject, half-octave frequency band, stimulus type, and stimulus level.

NONLINEAR TEOAES

In general, nonlinear TEOAEs performed well for stimulus levels from 38 to 50 dB SPL. Validity could perhaps be improved more by stricter requirements on what constitutes a good calibration. The 0.5 and 0.7 kHz half-octave bands tended to show more noise and artifact; stricter criteria for validity may be required at these frequencies.

Click (1 to 5 kHz)

The highest, clean stimulus level was 50 dB SPL from 0.7 to 5.6 kHz, (not including 0.5 kHz or Subject 1042).

- 0.5 to 0.7 kHz: some artifact was present down to 41 dB SPL.
- 1 to 4 kHz: Overall, stimulus levels of 50 dB SPL gave artifact free results. (Subject 1042 showed responses down to 44 dB SPL.)
- 5.6 kHz: all measurements were artifact free.

Click (1 to 2.5 kHz)

The highest, clean stimulus level was 53 dB SPL from 1.4 to 5.6 kHz, providing the low-pass response filter was lowered to 3 kHz (this removed artifact for one subject). (Subject 1042 showed OAE responses at lower frequencies.)

- 0.5 kHz: some very low-level responses that can be safely ignored.
- 0.7 to 1 kHz: Subject 1041 showed low-frequency artifact and high noise levels (depending on stimulus level), which appeared to come from an unstable spectral calibration through 0.5 to 1 kHz. The spectral calibration introduced group delays at some frequencies that extended out to 2 ms or more. This should be something that can be automatically detected. It is possibly due to a leak in the probe fit that the spectral calibration has not been able to compensate.
- 1.4 to 2 kHz: all good measurements at 50 dB SPL were artifact free. Subject 1035 had a missing data point due to noise. (Subject 1042 showed some OAE responses.)
- 2.8 to 4 kHz: Subject 1035 showed some artifact at the highest stimulus level. It may be coming from a high side-lobe in the TEOAE stimulus (side lobe ranges from 3.5 to 5 kHz; see Figure 8). Lowering the low-pass filter cutoff to 3 kHz removed this artifact (though dealing with the source would be a preferable solution). All other subjects (including Subject 1042) showed no artifact at these frequencies.
- 5.6 kHz: all measurements were artifact free.

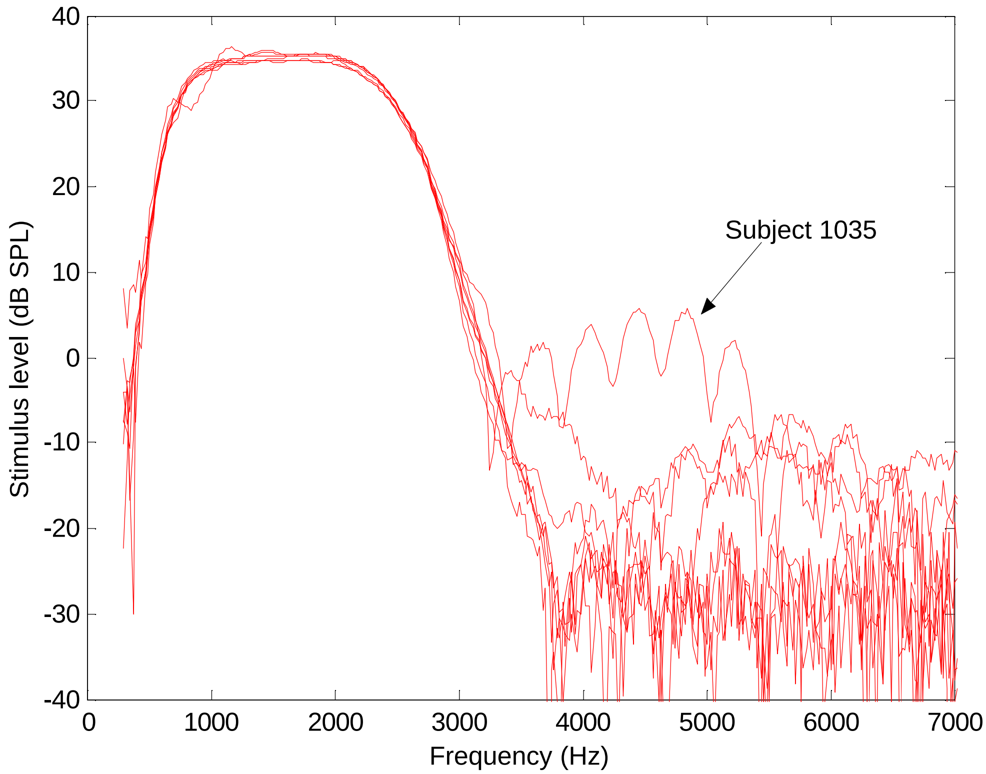

Figure 8. Stimulus spectra for non-linear Clicks (1-2.5 kHz) at 53 dB SPL. Note the high side-lobes for Subject 1035.

Dau Chirp (1 to 5 kHz)

Dau Chirps can be measured without artifact up to 50 dB SPL for frequencies 1 through 5.6 kHz (ignoring Subject 1042), though with a couple of missing data points, this cannot be claimed with certainty.

- 0.5 to 1.4 kHz: Subject 1035 had a high noise floors for 53 dB SPL, but no lower levels were tested so we cannot say for sure that there was no artifact present for this subject. Subject 1041 showed a mix of artifact and noise. (Subject 1042 showed some OAE-like responses.)
- 2 to 2.8 kHz: all good measurements were artifact free.
- 4 kHz: Subject 1041 showed artifact in this band in the same frequency region as the probe artifact. Normally this artifact is removed in the non-linear mode, but this was not the case at the highest stimulus level. Lower stimulus levels showed no artifact.
- 5.6 kHz: all measurements were artifact free.

Shera Chirp (1 to 5 kHz)

These chirps performed well, with no artifact at 53 dB SPL. No lower stimulus levels were tested. There were some missing data points due to noise in the half-octave frequency bands of 1, 1.4, and 2 kHz from Subjects 1029, 1035, and 1041. Because no lower levels were tested, we cannot say for sure that these frequencies are artifact free. However, with the very clean results at other frequencies (which showed artifact for other TEOAE types), it is most likely that these chirps can be tested safely up to 53 dB SPL.

LINEAR TEOAES

In general, linear TEOAEs showed much more artifact at most levels compared with the same stimuli presented in nonlinear mode. The probe artifact in the 4 kHz half-octave band was present in most cases, and in some measurements was quite pronounced (over 15 dB SNR in some cases). This appeared to possibly coincide with small ripples in the group delay spectrum (from the spectral calibration), but it is difficult to say with certainty whether this had any bearing because the ripples did not differ by more than about 1 ms. Extending the start of the data window did reduce many artifacts, but it is likely to also remove real TEOAE components. The optimal placement of the start of the data window needs further investigation in normal-hearing ears.

Click (1 to 5 kHz)

This condition was run using both forms of calibration – spectral calibration and normal calibration. The focus here is on spectral calibration – the comparison of calibration types is on Page 13.

- 0.5 to 2.8 kHz: three subjects (besides Subject 1042) had artifact at some frequency across all levels.
- 4 kHz: the artifact at this frequency was primarily due to a linear probe artifact (it mostly disappeared in non-linear mode).
- 5.6 kHz: all measurements were artifact free.

Click (1 to 2.5 kHz)

With the additional delay to the start of the window (from 2 to 4 ms), much of the artifact seen in the preliminary results was reduced considerably. It may be possible to remove even more artifact by further delaying the window, but this would need to be done in conjunction with measurements made on normal-hearing ears to see how much, if any, TEOAE response was lost. It may also be possible to tweak the stimulus further and perhaps soften the roll-off at 2.5 kHz.

- 0.5 to 1 kHz: artifact is present down to 41 dB SPL in two subjects (other than Subject 1042). There were also some ambiguous results at 1 kHz, where artifact appeared at lower, but not higher levels.

- 1.4 kHz: no artifact from 50 dB SPL down.
- 2 kHz: one subject had artifact down to 47 dB SPL (from what appeared to be stimulus ringing). By moving the start of the time window out to 5 ms, the artifact was removed. It remains to be seen in normal-hearing ears whether this would cause the loss of any TEOAE response.
- 2.8 to 5.6 kHz: no artifact. This is not surprising because the stimulus rolled off at 2.5 kHz so there were no high frequency components.

Dau Chirp (1 to 5 kHz)

Subject 1035's data were discarded because not enough averages were collected.

Extending the data window out to 3 ms removed more artifacts. This may or may not remove true TEOAEs (due to the group delays of the various frequency components) – this would need to be evaluated in conjunction with measurements made on normal-hearing ears to see how much, if any, TEOAE response was lost. Extending the time window also reduced the probe artifact at 4 kHz.

- 0.5 to 0.7 kHz: there were fewer artifacts at these low frequencies than for clicks.
- 1 kHz: there was artifact down to 47 dB SPL (not including Subject 1042). There were also some ambiguous results at 1 kHz, where artifact appeared at lower, but not higher levels.
- 1.4 kHz: remaining data (except Subject 1042) was artifact free at 50 dB SPL.
- 2 kHz: subject 1037 showed artifact down to 41 dB SPL.
- 2.8 kHz: remaining data (except Subject 1042) was artifact free at 47 dB SPL.
- 4 kHz: probe artifact affected most subjects across all stimulus levels.
- 5.6 kHz: artifact free at all levels.

Shera Chirp (1 to 5 kHz)

In general, Shera chirps in linear mode were well behaved. Subjects 1028 and 1029 both had all data discarded for the 53 dB SPL level, but their results were all artifact free at 50 dB SPL, except at 4 kHz where there was a probe artifact. Subject 1035's data was discarded because not enough averages were collected.

- 0.5 to 1.4, & 2.8 & 5.6 kHz: all subjects with good measurements were artifact free at 50 dB SPL (ignoring Subject 1042).
- 2 kHz: Subject 1037 showed artifact down to 47 dB SPL.
- 4 kHz: probe artifact affected all levels.

TEOAEs measured in nonlinear mode, for all stimulus types tested, had little to no artifact for stimulus levels from 38 to 50 dB SPL. TEOAEs measured in linear mode, on the other hand, showed artifact for some subjects at quite low stimulus levels. Although some subjects had relatively clean linear TEOAE results, there were too many subjects showing artifact (and not in any particularly consistent fashion) to ensure valid results in general.

The 4 kHz artifact in linear mode was due to a linear probe artifact. The frequency where this artifact differs across ER10C probes, but appears to affect all ER10C probes to a greater or lesser extent. This artifact is easily detectable in a syringe or acoustic coupler. These probes were not designed with transient stimuli in mind. Instead, they were designed for measuring DPOAEs, which use long-duration, tonal stimuli. Future probe development must take into consideration the impulse response, with aim to damp the response if the probe is to be used for transient stimuli.

Why did chirps show fewer artifacts than clicks? The reasons why are possibly due to the crest factor (peak to rms ratio) and duration of the chirps. The lower peak level and longer duration means that (a) the probe is not hit with such a large impulse and (b) the low frequency artifact is diminished by the time the chirp has finished (i.e., before the data window begins). Shera Chirps gave the least artifact in this experiment. But, the big question is whether these chirps give the best OAE measurements in normal-hearing people.

It is difficult to compare the validity of the Mimosa system to that of the ILO system, because the lower noise floor of the Mimosa system means more low-level artifacts are detectable. If these types of artifacts are also present in the ILO system, they would not be detectable due to the higher noise floor.

TEOAE validity will be reconsidered once the reliability and measurability of TEOAEs in normal-hearing ears is analyzed. That is, if the subsequent analyses show that a different combination of response data-windowing and/or filtering is required, then the validity analyses should be rerun with these parameters.

References

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Appendix A gives seven examples of the behavior of the various TEOAE stimuli in an acoustic coupler (2cc syringe) using the same probe as for the hearing-impaired subjects (ER10C #1210). All examples were for the highest stimulus level of 53 dB SPL and all used spectral calibration. Notice how the stimulus spectra were identical (except for the narrower click) but the group delay and time-domain waveforms differed considerably for clicks and chirps (also see the examples in the Introduction).

The low frequency artifact seen in nonlinear mode is probably due to the different gain factors used. The linear mode was run with 0 dB gain to reduce linear artifact at the price of an increase in the noise floor. The nonlinear mode was run with 18 dB gain, which appeared to bump the very low frequency noise but with lower noise overall (the comparison cannot be made directly here because there were only 500 averages taken in nonlinear mode compared with 2000 in linear mode).[3]

The narrower click (1 to 2.5 kHz) had a much higher low-frequency artifact compared with the wider click (1 to 5 kHz). This may be due to the higher spectrum level (rms SPL is matched for all stimuli, which results in the same spectrum level only if the bandwidth is identical). Note too that this artifact is mostly removed by increasing the window start to 4 ms post-stimulus. This is indeed what was done for the measurements made in hearing-impaired ears.

Notes on the first page describe the information displayed in the summary printouts.

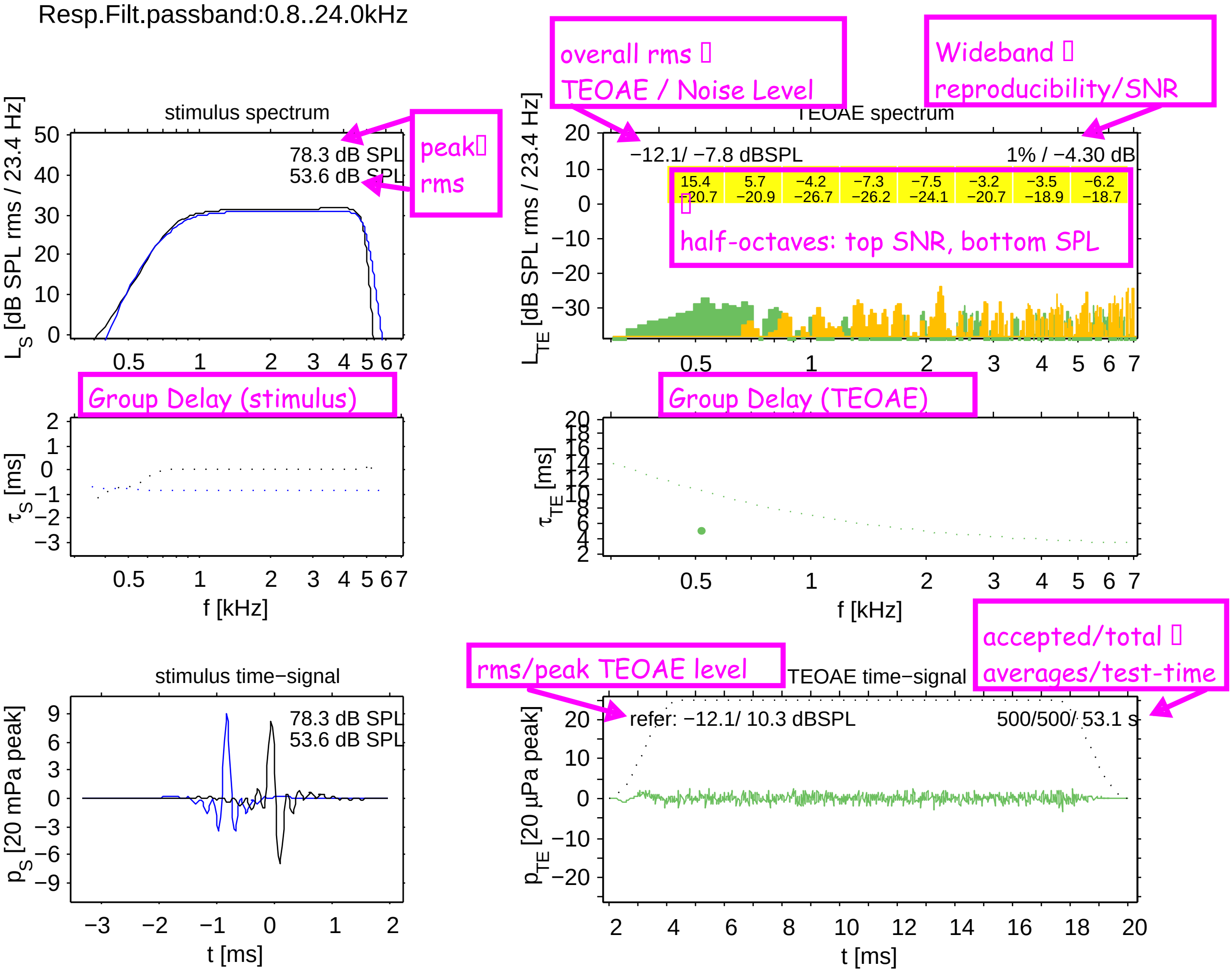
Stimulus Description	Protocol	Notes
Click 1 to 5 kHz nonlinear mode	V1ClickNL	Only low frequency artifact
Dau Chirp 1 to 5 kHz nonlinear mode	V2DauNL	No artifact
Shera Chirp 1 to 5 kHz nonlinear mode	V3SheraNL	No artifact
Click 1 to 5 kHz linear mode	V4ClickLN	Probe artifact in 4 kHz band present
Dau Chirp 1 to 5 kHz linear mode	V5DauLN	Probe artifact in 4 kHz band present
Shera Chirp 1 to 5 kHz linear mode	V6SheraLN	Probe artifact in 4 kHz band present
Click 1 to 2.5 kHz nonlinear mode	V7JudiNL	Much higher low frequency artifact

[3] The two modes were equated for test time rather than for the number of averages. Note that nonlinear mode requires the presentation of 2000 waveforms for a total of 500 averages.

T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:10:19	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V1ClickNL53"; Stim.: Custom [white,flat] 1.0..5.0kHz;
Level: 53 [max 61] dB SPL RMS; Subavg: 4 [+3,−1]; Interstim.Pause: 20.0 ms;
Stim.Inv.Epoch: 10; Stim.Channel: 1; Subpos: 4, Pol.: 1, Delay: 2 ms;
Npass: 500= 53.083 s ; Nremeasure: 400= 42.467 s ; Gain: 18.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1274;
Resp.Filt.passband:0.8..24.0kHz



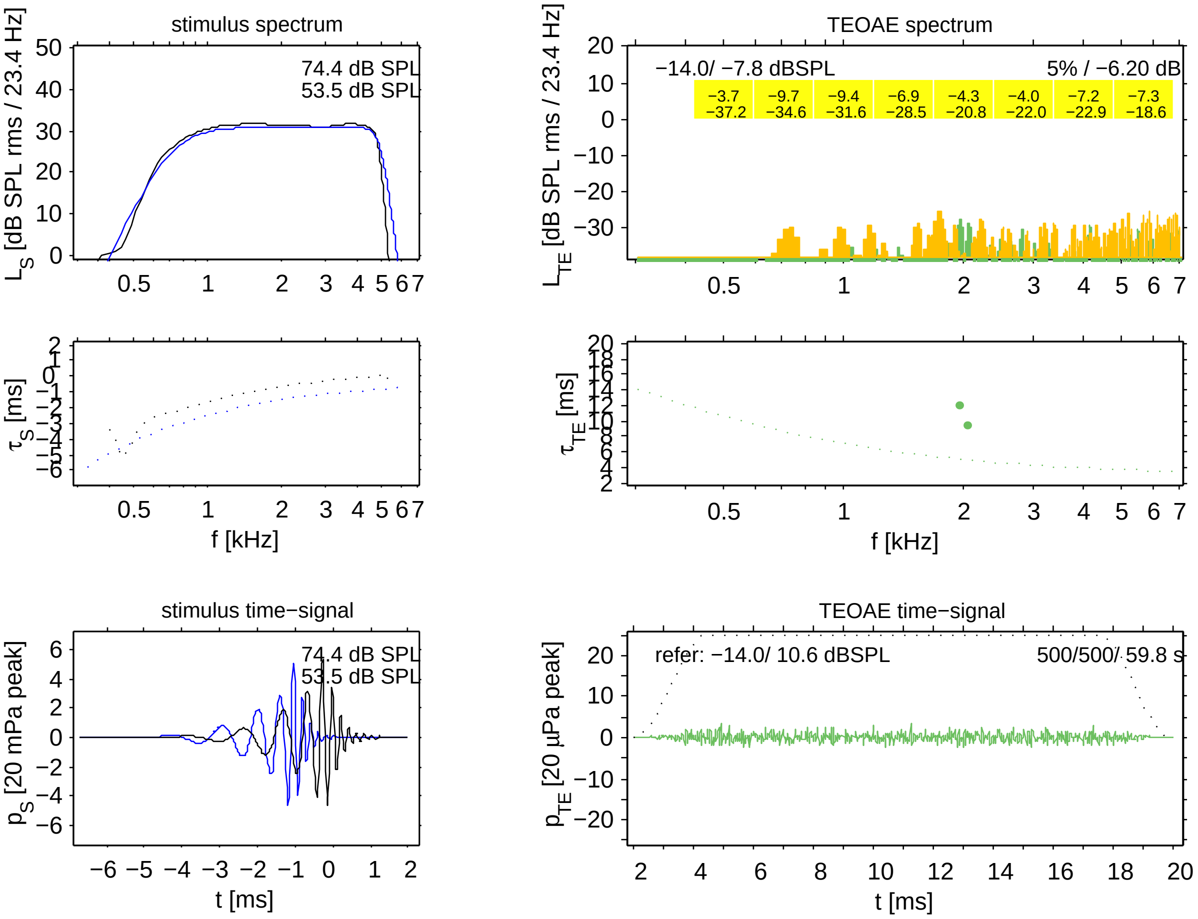
Comments:
Testing syringe ER10C 1210

NSMRL
Groton, CT

T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:12:27	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V2DauNL53"; Stim.: Custom [white,Dau] 1.0..5.0kHz;
Level: 53 [max 67] dB SPL RMS; Subavg: 4 [+3,−1]; Interstim.Pause: 20.0 ms;
Stim.Inv.Epoch: 10; Stim.Channel: 1; Subpos: 4, Pol.: 1, Delay: 2 ms;
Npass: 500= 59.833 s ; Nremeasure: 400= 47.867 s ; Gain: 18.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1436;
Resp.Filt.passband:0.8..24.0kHz



Comments:

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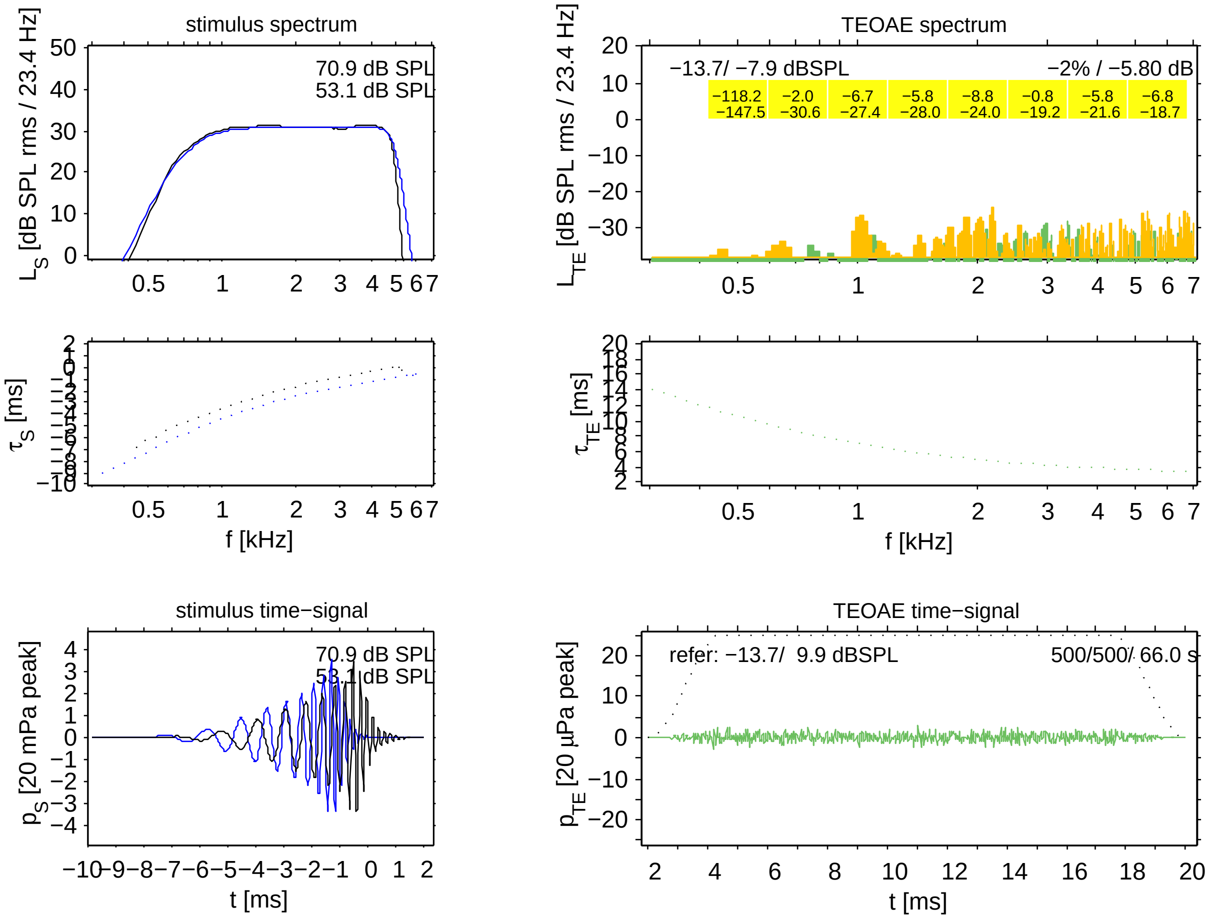
T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:14:11	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V3SheraNL53"; Stim.: Custom [white,Shera] 1.0..5.0kHz;
Level: 53 [max 70] dB SPL RMS; Subavg: 4 [+3,−1]; Interstim.Pause: 20.0 ms;
Stim.Inv.Epoch: 10; Stim.Channel: 1; Subpos: 4, Pol.: 1, Delay: 2 ms;
Npass: 500= 66.042 s ; Nremeasure: 400= 52.833 s ; Gain: 18.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1585;
Resp.Filt.passband:0.8..24.0kHz



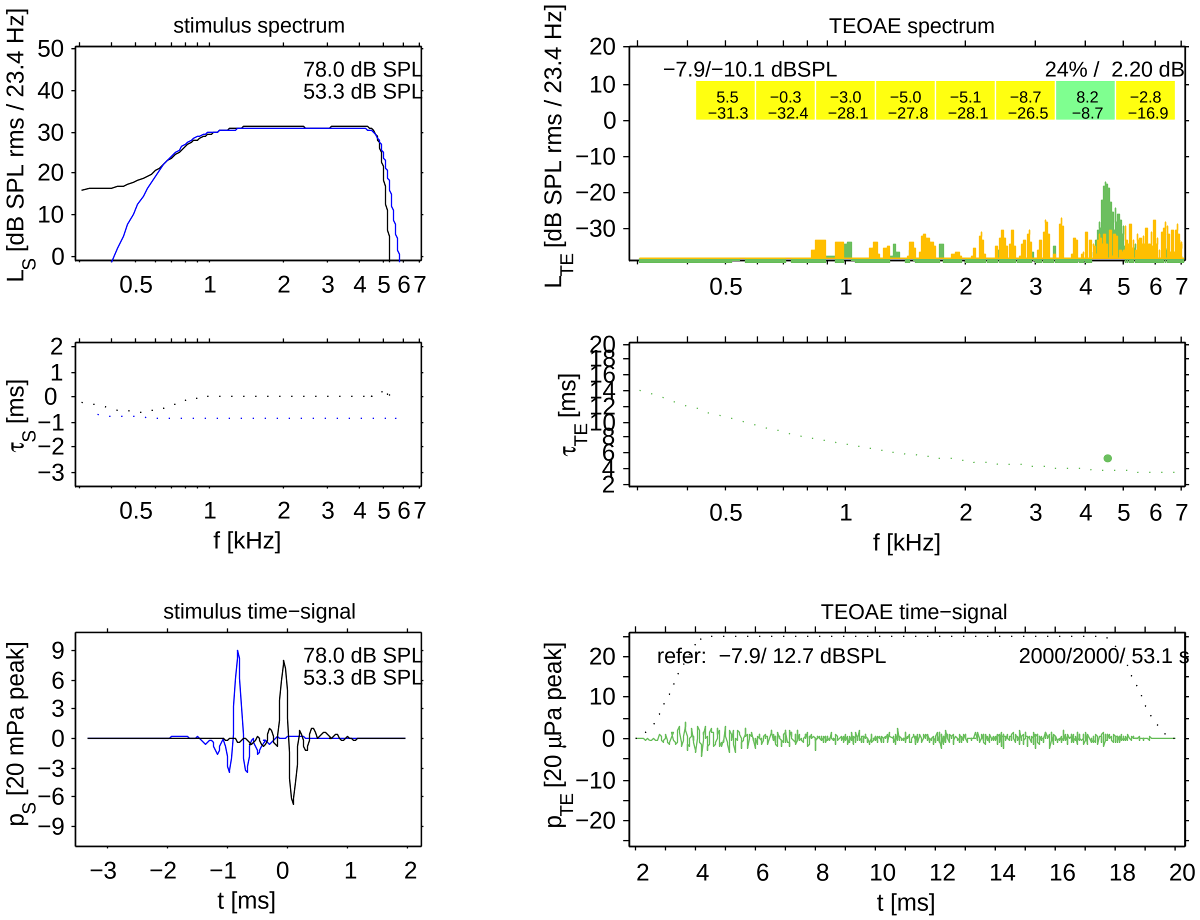
Comments:

NSMRL
Groton, CT

T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:15:47	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V4ClickLN53"; Stim.: Custom [white,flat] 1.0..5.0kHz;
Level: 53 [max 71] dB SPL RMS; no subavg; Interstim.Pause: 20.0 ms; Stim.Inv.Epoch: 10;
Stim.Channel: 1; Subpos: 1, Pol.: 1, Delay: 2 ms; Npass: 2000= 53.083 s ;
Nremeasure: 400= 10.617 s ; Gain: 0.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1274;
Resp.Filt.passband:0.8..24.0kHz



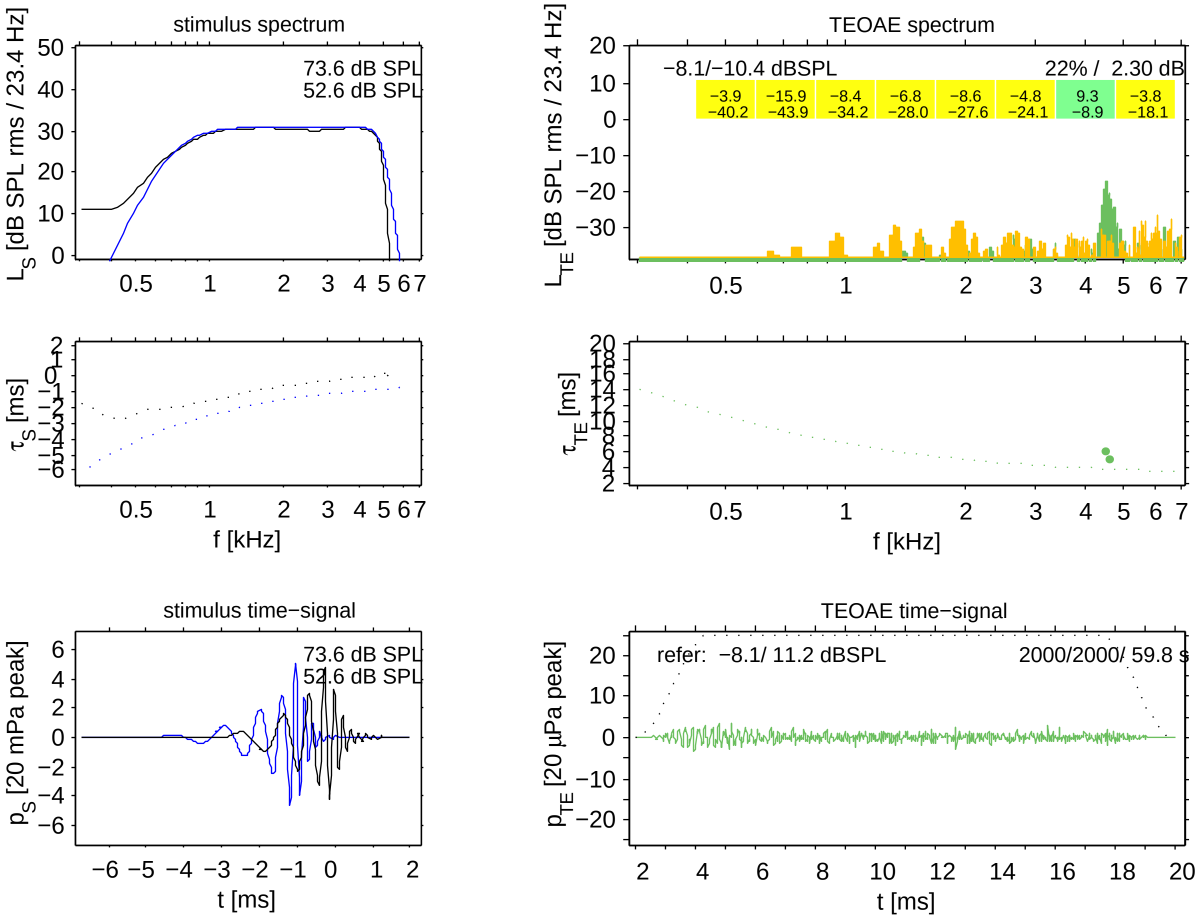
Comments:

NSMRL
Groton, CT

T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:21:39	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V5DauLN53"; Stim.: Custom [white,Dau] 1.0..5.0kHz;
Level: 53 [max 78] dB SPL RMS; no subavg; Interstim.Pause: 20.0 ms; Stim.Inv.Epoch: 10;
Stim.Channel: 1; Subpos: 1, Pol.: 1, Delay: 2 ms; Npass: 2000= 59.833 s ;
Nremeasure: 400= 11.967 s ; Gain: 0.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1436;
Resp.Filt.passband:0.8..24.0kHz



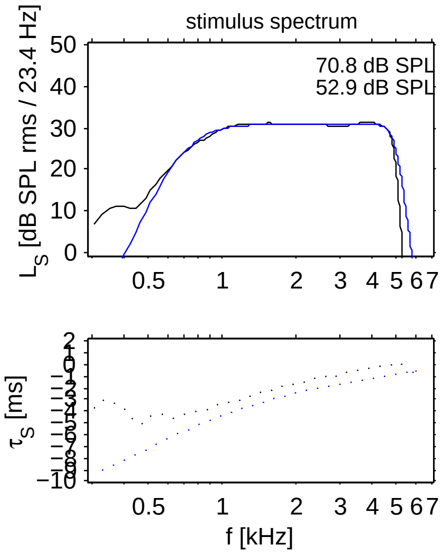
Comments:

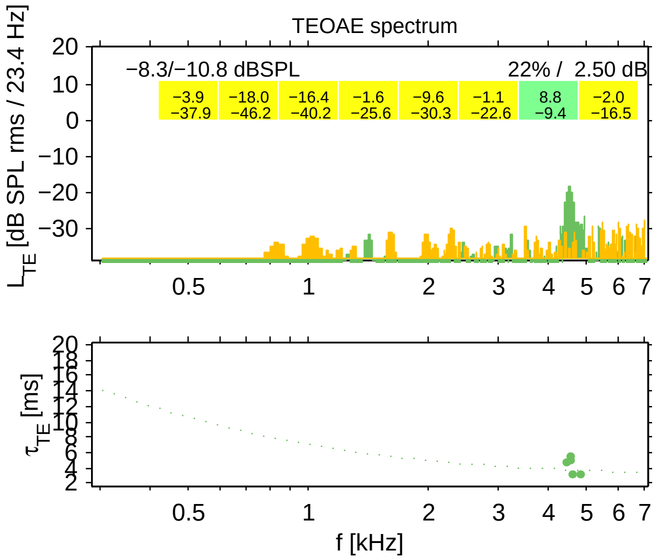
NSMRL
Groton, CT

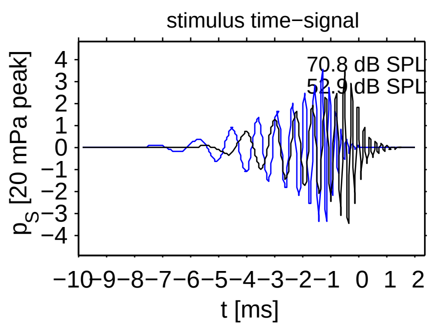
T2K TEOAE Test Summary

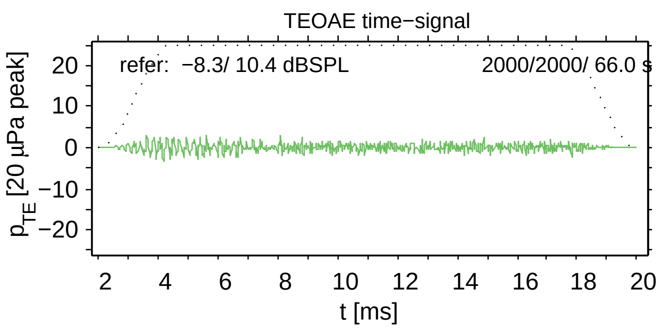
Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:28:01	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V6SheraLN53"; Stim.: Custom [white,Shera] 1.0..5.0kHz;
Level: 53 [max 80] dB SPL RMS; no subavg; Interstim.Pause: 20.0 ms; Stim.Inv.Epoch: 10;
Stim.Channel: 1; Subpos: 1, Pol.: 1, Delay: 2 ms; Npass: 2000= 66.042 s ;
Nremeasure: 400= 13.208 s ; Gain: 0.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1585;
Resp.Filt.passband:0.8..24.0kHz









Comments:

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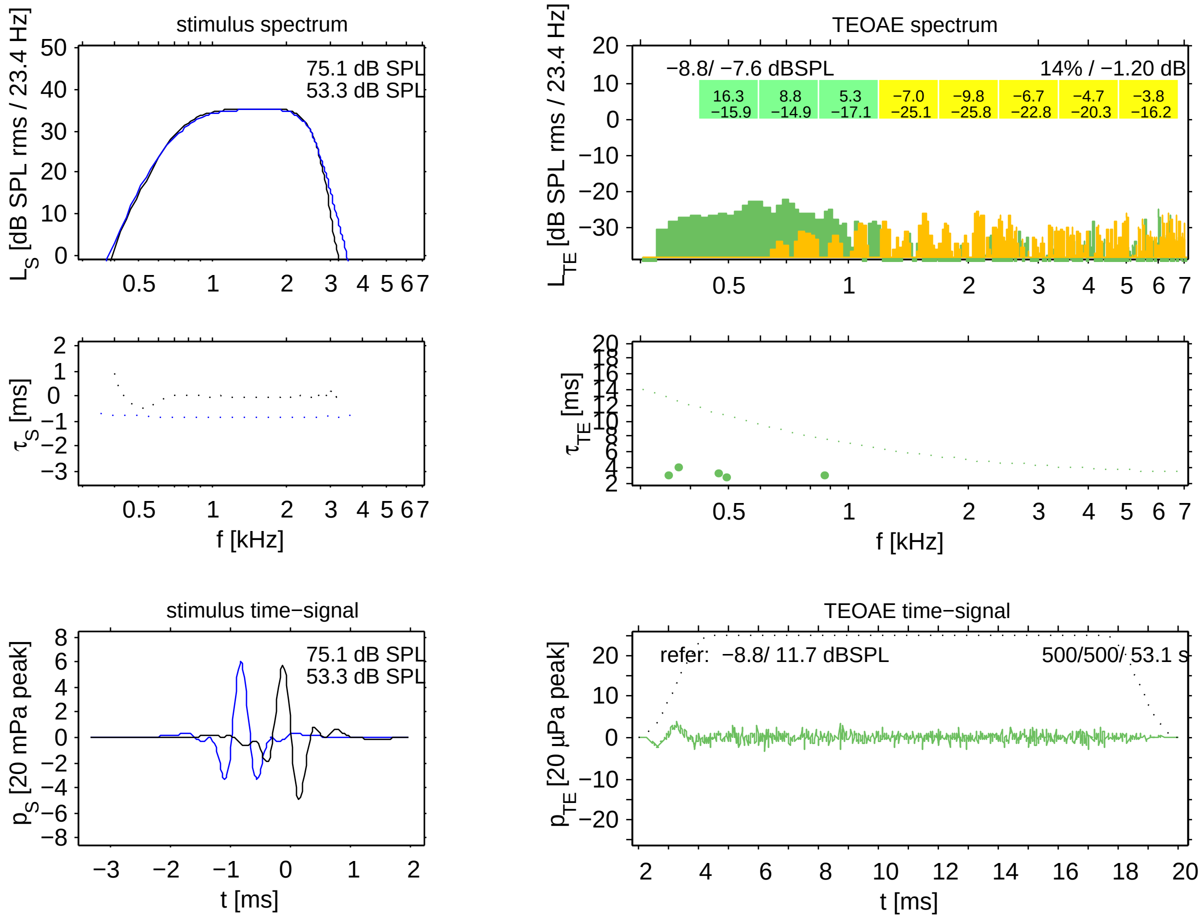
T2K TEOAE Test Summary

Patient ID:	1210	Patient name:	1210 ER10C
Date of birth:	7/16/03	Clinician:	NSMRL
Date of test:	08/04/2003 15:34:57	System ID:	unknown
Test ear:	L		

Parameters:
Protocol: "V7JudiNL53"; Stim.: Custom [white,flat] 1.0..2.5kHz;
Level: 53 [max 61] dB SPL RMS; Subavg: 4 [+3,−1]; Interstim.Pause: 20.0 ms;
Stim.Inv.Epoch: 10; Stim.Channel: 1; Subpos: 4, Pol.: 1, Delay: 2 ms;
Npass: 500= 53.083 s ; Nremeasure: 400= 42.467 s ; Gain: 18.0 dB; check overflow: Yes;
A.Rej.crit.: 40.0 dB SPL; Samp.Rate: 48000 Hz; Buf.Length: 1274;
Resp.Filt.passband:0.8..24.0kHz



Comments:

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Groton, CT

Remember when viewing these tables that Subject 1042 was thought to have some residual cochlear function, so her results should be interpreted separately from the others.

These tables are indexed by protocol name as follows:

Stimulus Description	Protocol
Click 1 to 5 kHz nonlinear mode	V1ClickNL
Click 1 to 2.5 kHz nonlinear mode	V7JudiNL
Dau Chirp 1 to 5 kHz nonlinear mode	V2DauNL
Shera Chirp 1 to 5 kHz nonlinear mode	V3SheraNL
Click 1 to 5 kHz linear mode, spectral calibration	V4ClickLN (spec cal)
Click 1 to 5 kHz linear mode, normal calibration	V4ClickLN (norm cal)
Click 1 to 2.5 kHz linear mode	V8JudiLN
Dau Chirp 1 to 5 kHz linear mode	V5DauLN
Shera Chirp 1 to 5 kHz linear mode	V6SheraLN

Wideband

Stimulus Level (dB SPL)

V1ClickNL	53	50	47	44	41	38
1024	x	.	.	.	.	.
1028	x	x	.	.	.	.
1029	x	.	.	.	.	.
1035	NF	.	.	.	.	.
1037	x	x	.	.	.	.
1038	x	x	.	.	.	.
1041	x	x	x	NF	x	x
1042	A	A	A	A	x	.

V2DauNL	53	50	47	44	41	38
1024	x	.	.	.	.	.
1028	x	.	.	.	.	.
1029	x	.	.	.	.	.
1035	x	.	.	.	.	.
1037	x	.	.	.	.	.
1038	x	x	x	.	.	.
1041	NF	x	NF	x	.	.
1042	A	x	x	.	.	.

V3SheraNL	53	50	47	44	41	38
1024	x	.	.	.	.	.
1028	x	.	.	.	.	.
1029	x	.	.	.	.	.
1035	x	.	.	.	.	.
1037	x	.	.	.	.	.
1038	x	.	.	.	.	.
1041	x	.	.	.	.	.
1042	x	.	.	.	.	.

V4ClickLN(speccal)	53	50	47	44	41	38
1024	A	A	x	x	x	x
1028	A	A	A	A	x	x
1029	A	A	x	x	x	x
1035	A	A	x	x	x	x
1037	A	A	A	A	x	.
1038	A	A	x	x	x	x
1041	A	A	A	A	x	x
1042	A	A	A	A	A	x

V4ClickLN(normcal)	53	50	47	44	41	38
1024	x	x	x	x	.	.
1028	A	.	.	.	.	.
1029	A	.	.	.	.	.
1035	A	A	x	x	x	.
1037	A	A	A	A	x	.
1038	x	x	x	x	x	x
1041	A	B	A	x	x	x
1042	A	A	A	A	A	x

Wideband — Stimulus Level (dB SPL)

V5DauLN	53	50	47	44	41	38
1024	A	x	x	x	x	.
1028	A	A	A	x	x	x
1029	A	A	A	x	x	x
1035	B	B	B	B	.	.
1037	A	A	x	x	x	x
1038	x	x	x	x	.	.
1041	A	A	A	A	x	x
1042	A	A	A	A	x	x

V6SheraLN	53	50	47	44	41	38
1024	x	x	x	x	.	.
1028	B	A	A	A	x	x
1029	B	A	A	x	x	x
1035	B	B	.	.	.	.
1037	x	x	x	.	.	.
1038	x	x	.	.	.	.
1041	A	A	A	x	x	x
1042	A	A	x	x	x	x

V7JudiNL	53	50	47	44	41	38
1024	x	x	x	.	.	.
1028	x	x	.	.	.	.
1029	x	x	x			
1035	x	B	B	.	.	.
1037	A	x	x	.	.	.
1038	x	x	x	.	.	.
1041	A	A	x	NF	.	.
1042	A	A	A	A	A	x

V8JudiLN	53	50	47	44	41	38
1024	A	A	x	x	x	x
1028	x	x	x	x	x	x
1029	A	A	x	x	x	x
1035	A	A	B	B	x	x
1037	A	A	A	A	A	x
1038	A	A	x	x	x	x
1041	A	B	A	A	x	A
1042	A	A	A	A	A	x

KEY

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
LW	Artifact is present but ignored because <-25 dB SPL
NF	High noise floor
B	Bad measurement (stimulus level bad or not enough averages)
.	No measurement made

Highest level which is artifact free (x or LW cells)
Artifact present (A cells)
Ambiguous due to missing data at higher level or because A appears at lower level than an x
Artifact present, but no good data at lower levels (A cells)
All data missing (B or NF cells)

Remember when viewing these tables that Subject 1042 was thought to have some residual cochlear function, so her results should be interpreted separately from the others.

These tables are indexed by protocol name as follows:

Stimulus Description	Protocol
Click 1 to 5 kHz nonlinear mode	V1ClickNL
Click 1 to 2.5 kHz nonlinear mode	V7JudiNL
Dau Chirp 1 to 5 kHz nonlinear mode	V2DauNL
Shera Chirp 1 to 5 kHz nonlinear mode	V3SheraNL
Click 1 to 5 kHz linear mode, spectral calibration	V4ClickLN (spec cal)
Click 1 to 5 kHz linear mode, normal calibration	V4ClickLN (norm cal)
Click 1 to 2.5 kHz linear mode	V8JudiLN
Dau Chirp 1 to 5 kHz linear mode	V5DauLN
Shera Chirp 1 to 5 kHz linear mode	V6SheraLN

Click (1 to 5 kHz): nonlinear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	LW					
0.5	1028	x	A				
0.5	1029	x					
0.5	1035	x					
0.5	1037	LW	LW				
0.5	1038	LW	x				
0.5	1041	A	A	x	A	x	x
0.5	1042	A	A	A	LW	x	
0.7071	1024	x					
0.7071	1028	x	x				
0.7071	1029	x					
0.7071	1035	NF					
0.7071	1037	x	x				
0.7071	1038	x	x				
0.7071	1041	A	NF	x	NF	NF	x
0.7071	1042	A	A	A	A	x	
1	1024	x					
1	1028	x	x				
1	1029	x					
1	1035	NF					
1	1037	x	x				
1	1038	x	x				
1	1041	NF	NF	NF	NF	NF	NF
1	1042	A	A	A	A	x	
1.4142	1024	x					
1.4142	1028	x	x				
1.4142	1029	x					
1.4142	1035	NF					
1.4142	1037	x	x				
1.4142	1038	x	x				
1.4142	1041	x	x	x	NF	x	NF
1.4142	1042	A	A	A	x	x	
2	1024	x					
2	1028	NF	x				
2	1029	x					
2	1035	x					
2	1037	A	x				
2	1038	x	x				
2	1041	x	x	x	NF	x	NF
2	1042	x	A	x	x	x	
2.8284	1024	x					
2.8284	1028	x	x				
2.8284	1029	x					
2.8284	1035	x					
2.8284	1037	x	x				
2.8284	1038	x	x				
2.8284	1041	x	x	x	x	x	x
2.8284	1042	A	x	x	x	x	
4	1024	x					
4	1028	x	x				
4	1029	x					
4	1035	NF					
4	1037	x	x				
4	1038	x	x				
4	1041	A	x	x	x	x	x
4	1042	x	x	x	x	x	
5.6569	1024	x					
5.6569	1028	x	x				
5.6569	1029	x					
5.6569	1035	x					
5.6569	1037	x	x				
5.6569	1038	x	x				
5.6569	1041	x	x	x	x	x	x
5.6569	1042	x	x	x	x	x	

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free	(x or LW cells)
Artifact present	(A cells)
Ambiguous: data missing at next level or A appears at lower level than x	
Artifact present,	but no good data at lower levels (A cells)
All data missing	(B or NF cells)

Click (1 to 2.5 kHz): nonlinear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	LW	LW	x			
0.5	1028	x	x				
0.5	1029	x	x	x	x	x	x
0.5	1035	x	x	B			
0.5	1037	x	x	x			
0.5	1038	x	x	LW			
0.5	1041	x	x	x	x		
0.5	1042	A	A	A	A	LW	LW
0.7071	1024	x	x	x			
0.7071	1028	x	x				
0.7071	1029	x	x	x	x	x	x
0.7071	1035	x	NF	B			
0.7071	1037	x	x	x			
0.7071	1038	x	x	x			
0.7071	1041	A	A	NF	NF		
0.7071	1042	A	A	A	A	A	A
1	1024	x	x	x			
1	1028	x	x				
1	1029	x	x	x	x	x	x
1	1035	NF	x	B			
1	1037	x	x	x			
1	1038	x	x	x			
1	1041	A	NF	NF	NF		
1	1042	A	A	A	A	A	A
1.4142	1024	x	x	x			
1.4142	1028	x	NF				
1.4142	1029	x	NF	x	NF	x	x
1.4142	1035	x	x	B			
1.4142	1037	x	x	x			
1.4142	1038	x	x	x			
1.4142	1041	x	NF	x	NF		
1.4142	1042	A	A	A	x	x	x
2	1024	NF	x	x			
2	1028	x	x				
2	1029	x	NF	x	x	x	x
2	1035	x	x	B			
2	1037	x	x	x			
2	1038	x	x	x			
2	1041	x	x	x	x		
2	1042	x	x	x	x	x	x
2.8284	1024	x	x	x			
2.8284	1028	x	x				
2.8284	1029	x	x	x	x	x	x
2.8284	1035	A	x	B			
2.8284	1037	x	x	x			
2.8284	1038	x	x	x			
2.8284	1041	x	x	x	x		
2.8284	1042	x	x	x	x	x	x
4	1024	x	x	x			
4	1028	x	x				
4	1029	x	x	x	x	x	x
4	1035	A	x	B			
4	1037	x	x	x			
4	1038	x	x	x			
4	1041	x	x	x	x		
4	1042	x	x	x	x	x	x
5.6569	1024	x	x	x			
5.6569	1028	x	x				
5.6569	1029	x	x	x	x	x	x
5.6569	1035	x	NF	B			
5.6569	1037	x	x	x			
5.6569	1038	x	x	x			
5.6569	1041	x	x	x	x		
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)
Artifact present (A cells)
Ambiguous: data missing at next level or A appears at lower level than x
Artifact present, but no good data at lower levels (A cells)
All data missing (B or NF cells)

Dau Chirp (1 to 5 kHz): nonlinear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	x					
0.5	1028	x					
0.5	1029	x					
0.5	1035	x					
0.5	1037	x					
0.5	1038	x	x	x			
0.5	1041	x	A	x	x		
0.5	1042	LW	x	x			
0.7071	1024	x					
0.7071	1028	x					
0.7071	1029	x					
0.7071	1035	x					
0.7071	1037	x					
0.7071	1038	x	x	x			
0.7071	1041	x	A	x	x		
0.7071	1042	A	A	x			
1	1024	x					
1	1028	x					
1	1029	x					
1	1035	NF					
1	1037	x					
1	1038	x	x	x			
1	1041	NF	NF	NF	NF		
1	1042	A	A	x			
1.4142	1024	x					
1.4142	1028	x					
1.4142	1029	x					
1.4142	1035	NF					
1.4142	1037	x					
1.4142	1038	x	x	x			
1.4142	1041	NF	NF	NF	NF		
1.4142	1042	A	A	x			
2	1024	x					
2	1028	x					
2	1029	x					
2	1035	x					
2	1037	x					
2	1038	x	x	x			
2	1041	x	x	NF	NF		
2	1042	x	x	x			
2.8284	1024	x					
2.8284	1028	x					
2.8284	1029	NF					
2.8284	1035	x					
2.8284	1037	x					
2.8284	1038	x	x	x			
2.8284	1041	x	x	x	x		
2.8284	1042	x	x	x			
4	1024	x					
4	1028	x					
4	1029	x					
4	1035	x					
4	1037	x					
4	1038	x	x	x			
4	1041	A	x	x	x		
4	1042	x	x	x			
5.6569	1024	x					
5.6569	1028	x					
5.6569	1029	x					
5.6569	1035	x					
5.6569	1037	x					
5.6569	1038	x	x	x			
5.6569	1041	x	x	x	x		
5.6569	1042	x	x	x			

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)
Artifact present (A cells)
Ambiguous: data missing at next level or A appears at lower level than x
Artifact present, but no good data at lower levels (A cells)
All data missing (B or NF cells)

Shera Chirp (1 to 5 kHz): nonlinear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	x					
0.5	1028	x					
0.5	1029	x					
0.5	1035	x					
0.5	1037	x					
0.5	1038	x					
0.5	1041	x					
0.5	1042	x					
0.7071	1024	x					
0.7071	1028	x					
0.7071	1029	x					
0.7071	1035	x					
0.7071	1037	x					
0.7071	1038	x					
0.7071	1041	x					
0.7071	1042	x					
1	1024	x					
1	1028	x					
1	1029	x					
1	1035	NF					
1	1037	x					
1	1038	x					
1	1041	NF					
1	1042	x					
1.4142	1024	x					
1.4142	1028	x					
1.4142	1029	x					
1.4142	1035	NF					
1.4142	1037	x					
1.4142	1038	x					
1.4142	1041	NF					
1.4142	1042	x					
2	1024	x					
2	1028	x					
2	1029	NF					
2	1035	NF					
2	1037	x					
2	1038	x					
2	1041	x					
2	1042	x					
2.8284	1024	x					
2.8284	1028	x					
2.8284	1029	x					
2.8284	1035	x					
2.8284	1037	x					
2.8284	1038	x					
2.8284	1041	x					
2.8284	1042	x					
4	1024	x					
4	1028	x					
4	1029	x					
4	1035	x					
4	1037	x					
4	1038	x					
4	1041	x					
4	1042	x					
5.6569	1024	x					
5.6569	1028	x					
5.6569	1029	x					
5.6569	1035	x					
5.6569	1037	x					
5.6569	1038	x					
5.6569	1041	x					
5.6569	1042	x					

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)	
Artifact present (A cells)	
Ambiguous: data missing at next leve or A appears at lower level than x	
Artifact present, but no good data at lower levels (A cells)	
All data missing (B or NF cells)	

Click (1 to 5 kHz): linear mode, spectrum calibration

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	LW	LW	x	LW	x	LW
0.5	1028	A	A	LW	LW	LW	x
0.5	1029	LW	LW	LW	LW	LW	x
0.5	1035	LW	LW	x	x	x	x
0.5	1037	LW	LW	x	LW	x	
0.5	1038	LW	x	LW	x	x	x
0.5	1041	A	A	A	LW	LW	LW
0.5	1042	A	A	A	LW	LW	LW
0.7071	1024	x	A	x	x	x	x
0.7071	1028	A	A	A	A	A	x
0.7071	1029	A	LW	x	x	x	x
0.7071	1035	A	x	x	x	x	x
0.7071	1037	x	x	x	x	x	
0.7071	1038	A	x	x	x	x	x
0.7071	1041	A	A	A	A	A	A
0.7071	1042	A	A	A	A	A	A
1	1024	A	A	A	A	x	x
1	1028	A	A	A	A	A	x
1	1029	A	A	A	A	A	x
1	1035	A	A	A	A	A	x
1	1037	x	x	x	x	x	
1	1038	A	A	A	A	A	A
1	1041	A	A	A	A	x	x
1	1042	A	A	A	A	A	A
1.4142	1024	A	A	A	x	x	x
1.4142	1028	A	A	x	x	x	x
1.4142	1029	A	A	x	x	A	x
1.4142	1035	A	A	A	A	A	x
1.4142	1037	A	x	x	x	x	
1.4142	1038	A	A	x	x	x	x
1.4142	1041	A	A	A	x	x	x
1.4142	1042	A	A	A	A	A	A
2	1024	A	x	x	x	x	x
2	1028	x	x	x	x	x	x
2	1029	x	x	x	x	x	x
2	1035	A	x	x	x	x	x
2	1037	A	A	A	A	A	
2	1038	x	x	x	x	x	x
2	1041	x	x	x	x	x	x
2	1042	A	A	A	A	A	x
2.8284	1024	A	x	x	x	x	x
2.8284	1028	x	x	x	x	x	x
2.8284	1029	x	x	x	x	x	x
2.8284	1035	x	x	x	x	x	x
2.8284	1037	A	A	A	x	x	
2.8284	1038	x	x	x	x	x	x
2.8284	1041	x	x	x	x	x	x
2.8284	1042	A	A	A	A	A	x
4	1024	A	A	A	x	x	x
4	1028	A	A	A	A	A	A
4	1029	A	A	A	A	A	A
4	1035	A	A	x	x	x	x
4	1037	A	A	A	x	x	
4	1038	A	x	x	x	x	x
4	1041	A	A	A	A	A	A
4	1042	A	A	A	A	A	x
5.6569	1024	x	x	x	x	x	x
5.6569	1028	x	x	x	x	x	x
5.6569	1029	x	x	x	x	x	x
5.6569	1035	x	x	x	x	x	x
5.6569	1037	x	x	x	x	x	
5.6569	1038	x	x	x	x	x	x
5.6569	1041	x	x	x	x	x	x
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

- Highest level which is artifact free (x or LW cells)
- Artifact present (A cells)
- Ambiguous: data missing at next level or A appears at lower level than x
- Artifact present, but no good data at lower levels (A cells)
- All data missing (B or NF cells)

Click (1 to 5 kHz): linear mode, normal calibration

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	LW	x	x	x		
0.5	1028	A					
0.5	1029	LW					
0.5	1035	x	x	x	x	x	
0.5	1037	LW	LW	LW	LW	LW	
0.5	1038	x	x	x	x	x	x
0.5	1041	A	B	A	LW	A	LW
0.5	1042	A	A	LW	LW	LW	LW
0.7071	1024	LW	x	LW	x		
0.7071	1028	A					
0.7071	1029	x					
0.7071	1035	x	x	x	x	x	
0.7071	1037	LW	x	x	x	x	
0.7071	1038	x	x	x	x	x	x
0.7071	1041	A	B	A	A	A	A
0.7071	1042	A	A	A	A	A	A
1	1024	A	A	A	x		
1	1028	A					
1	1029	A					
1	1035	x	x	x	x	x	
1	1037	x	x	x	x	x	
1	1038	A	x	x	x	x	LW
1	1041	A	B	A	A	A	x
1	1042	A	A	A	A	A	A
1.4142	1024	x	x	x	x		
1.4142	1028	x					
1.4142	1029	A					
1.4142	1035	x	x	x	x	x	
1.4142	1037	x	x	x	x	x	
1.4142	1038	A	x	x	x	x	x
1.4142	1041	A	B	A	x	x	x
1.4142	1042	A	A	A	A	A	x
2	1024	x	x	x	x		
2	1028	x					
2	1029	x					
2	1035	x	x	x	x	x	
2	1037	A	A	A	A	A	
2	1038	x	x	x	x	x	x
2	1041	x	B	x	x	x	x
2	1042	A	A	A	A	A	A
2.8284	1024	x	x	x	x		
2.8284	1028	x					
2.8284	1029	A					
2.8284	1035	x	x	x	x	x	
2.8284	1037	A	A	x	x	x	
2.8284	1038	x	x	x	x	x	x
2.8284	1041	A	B	x	x	x	x
2.8284	1042	A	A	A	A	A	A
4	1024	A	A	x	x		
4	1028	A					
4	1029	A					
4	1035	A	A	A	A	x	
4	1037	A	A	A	x	x	
4	1038	A	x	x	x	x	x
4	1041	A	B	A	x	x	x
4	1042	A	A	A	A	x	x
5.6569	1024	x	x	x	x		
5.6569	1028	x					
5.6569	1029	x					
5.6569	1035	x	x	x	x	x	
5.6569	1037	x	x	x	x	x	
5.6569	1038	x	x	x	x	x	x
5.6569	1041	x	B	x	x	x	x
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement	Highest level which is artifact free (x or LW cells)
A	Artifact is present (SNR>3dB)	Artifact present (A cells)
	No measurement made	Ambiguous: data missing at next level or A appears at lower level than x
NF	High noise floor	Artifact present, but no good data at lower levels (A cells)
B	Bad measurement	All data missing (B or NF cells)
LW	Artifact is present but ignored because it's less than <-25 dB SPL	

Click (1 to 2.5 kHz): linear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	LW	LW	x	x	x	x
0.5	1028	x	x	x	x	x	x
0.5	1029	LW	LW	x	x	x	x
0.5	1035	x	x	B	B	LW	x
0.5	1037	x	x	x	LW	x	x
0.5	1038	x	x	x	LW	LW	x
0.5	1041	A	B	A	A	LW	LW
0.5	1042	A	A	A	A	LW	LW
0.7071	1024	LW	x	LW	x	x	x
0.7071	1028	x	x	LW	x	x	x
0.7071	1029	x	x	x	x	LW	x
0.7071	1035	x	x	B	B	x	x
0.7071	1037	x	x	x	x	x	x
0.7071	1038	x	x	x	x	LW	x
0.7071	1041	A	B	A	A	A	x
0.7071	1042	A	A	A	A	A	A
1	1024	A	A	A	A	A	x
1	1028	x	x	x	x	x	x
1	1029	A	A	A	x	x	x
1	1035	x	A	B	B	x	x
1	1037	x	x	x	x	x	x
1	1038	x	x	x	A	x	x
1	1041	A	B	x	x	x	x
1	1042	A	A	A	A	A	A
1.4142	1024	x	x	x	x	x	x
1.4142	1028	x	x	x	x	x	x
1.4142	1029	A	x	x	x	x	x
1.4142	1035	A	x	B	B	x	x
1.4142	1037	x	x	x	x	x	x
1.4142	1038	x	x	x	x	x	x
1.4142	1041	x	B	x	x	x	x
1.4142	1042	A	A	A	A	A	x
2	1024	x	x	x	x	x	x
2	1028	x	x	x	x	x	x
2	1029	x	x	x	x	x	x
2	1035	A	x	B	B	x	x
2	1037	A	A	A	x	x	x
2	1038	x	x	x	x	x	x
2	1041	x	B	x	x	x	x
2	1042	A	x	A	x	x	x
2.8284	1024	x	x	x	x	x	x
2.8284	1028	x	x	x	x	x	x
2.8284	1029	x	x	x	x	x	x
2.8284	1035	x	x	B	B	x	x
2.8284	1037	x	x	x	x	x	x
2.8284	1038	x	x	x	x	x	x
2.8284	1041	x	B	x	x	x	x
2.8284	1042	x	x	x	x	x	x
4	1024	x	x	x	x	x	x
4	1028	x	x	x	x	x	x
4	1029	x	x	x	x	x	x
4	1035	x	x	B	B	x	x
4	1037	x	x	x	x	x	x
4	1038	x	x	x	x	x	x
4	1041	x	B	x	x	x	x
4	1042	x	x	x	x	x	x
5.6569	1024	x	x	x	x	x	x
5.6569	1028	x	x	x	x	x	x
5.6569	1029	x	x	x	x	x	x
5.6569	1035	x	x	B	B	x	x
5.6569	1037	x	x	x	x	x	x
5.6569	1038	x	x	x	x	x	x
5.6569	1041	x	B	x	x	x	x
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)
Artifact present (A cells)
Ambiguous: data missing at next level or A appears at lower level than x
Artifact present, but no good data at lower levels (A cells)
All data missing (B or NF cells)

Dau Chirp (1 to 5 kHz): linear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	x	LW	x	x	x	
0.5	1028	x	LW	x	x	x	x
0.5	1029	x	x	x	x	x	x
0.5	1035	B	B	B	B		
0.5	1037	x	x	x	x	x	x
0.5	1038	LW	x	LW	x		
0.5	1041	x	x	x	x	x	x
0.5	1042	A	LW	LW	LW	x	LW
0.7071	1024	A	x	x	x	x	
0.7071	1028	x	x	x	x	x	x
0.7071	1029	x	x	x	x	x	x
0.7071	1035	B	B	B	B		
0.7071	1037	x	x	x	x	x	x
0.7071	1038	A	x	LW	x		
0.7071	1041	A	x	x	x	x	x
0.7071	1042	A	A	A	A	A	LW
1	1024	A	A	A	x	x	
1	1028	x	A	x	x	x	x
1	1029	A	A	x	A	x	x
1	1035	B	B	B	B		
1	1037	x	x	x	x	x	x
1	1038	A	x	x	x		
1	1041	x	x	x	x	x	x
1	1042	A	A	A	A	A	A
1.4142	1024	A	x	x	x	x	
1.4142	1028	x	x	x	x	x	x
1.4142	1029	x	x	x	x	x	x
1.4142	1035	B	B	B	B		
1.4142	1037	x	x	x	x	x	x
1.4142	1038	x	A	x	x		
1.4142	1041	A	x	x	x	x	x
1.4142	1042	A	A	A	A	x	A
2	1024	x	x	x	x	x	
2	1028	x	x	x	x	x	x
2	1029	x	x	x	x	x	x
2	1035	B	B	B	B		
2	1037	A	A	A	A	A	x
2	1038	x	x	x	x		
2	1041	x	x	x	x	x	x
2	1042	A	A	A	A	x	x
2.8284	1024	x	x	x	x	x	
2.8284	1028	x	x	x	x	x	x
2.8284	1029	x	x	x	x	x	x
2.8284	1035	B	B	B	B		
2.8284	1037	A	A	x	x	x	x
2.8284	1038	x	x	x	x		
2.8284	1041	x	x	x	x	x	x
2.8284	1042	A	A	A	A	A	x
4	1024	A	A	A	x	x	
4	1028	A	A	A	A	A	A
4	1029	A	A	A	A	A	x
4	1035	B	B	B	B		
4	1037	A	A	A	x	x	x
4	1038	x	x	x	x		
4	1041	A	A	A	A	A	A
4	1042	A	A	A	A	A	x
5.6569	1024	x	x	x	x	x	
5.6569	1028	x	x	x	x	x	x
5.6569	1029	x	x	x	x	x	x
5.6569	1035	B	B	B	B		
5.6569	1037	x	x	x	x	x	x
5.6569	1038	x	x	x	x		
5.6569	1041	x	x	x	x	x	x
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)

Artifact present (A cells)

Ambiguous: data missing at next level or A appears at lower level than x

Artifact present, but no good data at lower levels (A cells)

All data missing (B or NF cells)

Shera Chirp (1 to 5 kHz): linear mode

Frequency	DisplayID	53 dB SPL	50 dB SPL	47 dB SPL	44 dB SPL	41 dB SPL	38 dB SPL
0.5	1024	x	x	x	x		
0.5	1028	B	x	x	x	x	x
0.5	1029	B	x	x	x	x	x
0.5	1035	B	B				
0.5	1037	x	x	x			
0.5	1038	x	x				
0.5	1041	x	x	x	x	x	x
0.5	1042	LW	LW	x	x	x	LW
0.7071	1024	x	x	x	x		
0.7071	1028	B	x	x	x	x	x
0.7071	1029	B	x	x	x	x	x
0.7071	1035	B	B				
0.7071	1037	x	x	x			
0.7071	1038	x	x				
0.7071	1041	x	x	x	x	x	x
0.7071	1042	A	A	LW	LW	LW	x
1	1024	x	x	x	x		
1	1028	B	x	x	x	x	x
1	1029	B	x	x	x	x	x
1	1035	B	B				
1	1037	x	x	x			
1	1038	x	x				
1	1041	x	x	x	x	x	x
1	1042	A	A	A	A	A	x
1.4142	1024	x	x	x	x		
1.4142	1028	B	x	x	x	x	x
1.4142	1029	B	x	x	x	x	x
1.4142	1035	B	B				
1.4142	1037	x	x	x			
1.4142	1038	x	x				
1.4142	1041	x	x	x	x	x	x
1.4142	1042	A	A	A	A	x	x
2	1024	x	x	x	x		
2	1028	B	x	x	x	x	x
2	1029	B	x	x	x	x	x
2	1035	B	B				
2	1037	A	A	x			
2	1038	x	x				
2	1041	x	x	x	x	x	x
2	1042	A	A	x	x	x	x
2.8284	1024	x	x	x	x		
2.8284	1028	B	x	x	x	x	x
2.8284	1029	B	x	x	x	x	x
2.8284	1035	B	B				
2.8284	1037	x	x	x			
2.8284	1038	x	x				
2.8284	1041	x	x	x	x	x	x
2.8284	1042	A	A	x	x	x	x
4	1024	A	A	x	x		
4	1028	B	A	A	A	A	A
4	1029	B	A	A	A	A	x
4	1035	B	B				
4	1037	A	A	x			
4	1038	x	x				
4	1041	A	A	A	A	A	A
4	1042	A	A	x	x	x	x
5.6569	1024	x	x	x	x		
5.6569	1028	B	x	x	x	x	x
5.6569	1029	B	x	x	x	x	x
5.6569	1035	B	B				
5.6569	1037	x	x	x			
5.6569	1038	x	x				
5.6569	1041	x	x	x	x	x	x
5.6569	1042	x	x	x	x	x	x

x	No artifact; good measurement
A	Artifact is present (SNR>3dB)
	No measurement made
NF	High noise floor
B	Bad measurement
LW	Artifact is present but ignored because it's less than <-25 dB SPL

Highest level which is artifact free (x or LW cells)
Artifact present (A cells)
Ambiguous: data missing at next level or A appears at lower level than x
Artifact present, but no good data at lower levels (A cells)
All data missing (B or NF cells)

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14. ABSTRACT

The validity of transient-evoked otoacoustic emissions needed to be determined for click and chirp stimuli implemented on the Mimosa Acoustics T2K Measurement System. The validity of transient-evoked otoacoustic emissions was evaluated for the Mimosa Acoustics T2K Measurement System v3.1.3 in eight hearing-impaired ears. These ears should not produce TEOAEs, so any responses are likely to be due to measurement artifact. Click and chirp stimuli showed acceptable validity for stimulus levels from 38 to 50 dB SPL when the stimuli were presented in the nonlinear mode. Validity was not acceptable in linear mode. Transient-evoked otoacoustic emissions are sounds made by healthy inner ears to transient stimulation. They are thought to hold the potential for diagnosis and monitoring of noise-induced hearing loss in military hearing-conservation programs. Choosing TEOAE stimuli for use in hearing-conservation programs must include considering the validity of the measurement. This is to ensure that the measured TEOAEs are due to responses made by the inner ear and are not artifacts.

15. SUBJECT TERMS

otoacoustic, otoacoustic emissions, evoked otoacoustic emissions, transient-evoked otoacoustic emissions, hearing conservation

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